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Smart Farming

Designing a Sensor Device for Agricultural Environment

Adriane Wassmansdorf Mattos

Final Project Work developed for the attribution of the degree of Master in Product Design
Final document

Trabalho Final de Projecto elaborado para a obtenção do grau de Mestre em Design de Produto
Documento definitivo

Panel/*Júri*: Carlos Oliveira Santos, Ph.D (Mentor/*Orientador*)
Paulo Alexandre dos Santos Dinis, Ph.D (Panel head/*Presidente do júri*)
António José Morais, Ph.D (Member/*Vogal*)

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“I would rather lose money than trust”
ROBERT BOSCH

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ABSTRACT

In the recent years, the steady growth of smart technologies is evident, as increasingly connected objects are emerging on the market. The resulting intelligent devices are not just changing consumers' lives, but also how industries are developing products and services that have the power to change the entire users' experience. Simultaneously, the Internet of Things (IoT) enables the creation of an ecosystem that connects physical and digital things by allowing them to act and interact with one another. In this sense, industries need to reinvent their system in order to catch up with this new digital era and embrace new challenges that will give them advantage related with the increase of productivity and profitability.

The problem is that, with the urge of creating products that can compete in the market, many companies fail to understand their customers, and smart devices end up not addressing users' needs. The focus need to be on creating technologies that enables people to achieve more and deliver a better performance, and this can be obtained by putting users' first in the development process.

In the last two years, the company Bosch has carried two studies with the aim of identifying farmers' needs towards new technologies in agriculture. The research led to the creation of two sensor devices that served as the foundation for this Final Project Work, which the main purpose was the creation of a universal sensor device based on the rich information gathered in the previous projects developed by Bosch. In order to achieve this, the designer was immersed in the farmers' context by embracing a experimental user-centered approach through the whole design process.

Keywords: *product design, user-centered approach, smart technology, sensor device, agriculture.*

RESUMO

No campo da oferta de objectos conectados entre si pela Internet, torna-se evidente, nos últimos anos, o crescimento de tecnologias inteligentes capazes de mudar a vida das pessoas, bem como de gerar indústrias que desenvolvam inúmeros produtos e serviços, susceptíveis de transformar as experiências que se processam entre os objecto e os utilizadores. Esta Internet das coisas (IoT) permite a criação de ecossistemas que conectam objectos físicos e digitais, possibilitando uma interacção entre eles. Assim sendo, as indústrias precisam reinventar os seus sistemas para que consigam alcançar esta nova era digital e abraçar novos desafios, que as irão favorecer, na perspectiva da inovação, do crescimento da produtividade e da rentabilidade.

Porém, com a urgência de criar novos produtos com potencial para competir nestes mercados, muitas empresas não se preocupam em investir tempo e processos adequados, que visem o conhecimento dos seus clientes, pelo que muitos objectos inteligentes acabam por fracassar, na perspectiva dos mercados. As empresas precisam, pois, focar-se na criação de tecnologias que permitam melhor desempenho e melhores resultados para os seus clientes. Este objectivo pode ser alcançado quando as empresas, no processo de desenvolvimento de produto e serviços, colocam o utilizador em primeiro lugar.

A empresa Bosch realizou, nos últimos dois anos, duas pesquisas, que tiveram como objectivo identificar as necessidades de agricultores na sua em relação com novas tecnologias para a agricultura. Essas pesquisas tiveram como resultado dois dispositivos sensoriais, que serviram de base a esta dissertação, que teve como objectivo a criação de um dispositivo sensorial universal. Para o alcançar, o designer esteve imerso no mundo dos agricultores, com base numa abordagem metodológica experimental e participativa, centrada nas necessidades dos respectivos utilizadores.

Palavras-chave: *design de produto, abordagem centrada no utilizador, tecnologia inteligente, sensor, agricultura.*

ACKNOWLEDGMENTS

Although the whole process is, essentially, an individual journey, it is impossible to successfully accomplish it without support and cooperation.

First, I would like to thank Bosch, for entrusting me with this challenging task, for providing me with a great and dynamic environment, and for giving me support through the whole process. I would also like to express my special thanks to Maximilian Einöder and Bernd Wiesenauer for giving me this opportunity.

And also to my professors at Delft University of Technology, for showing the user experience world, which today I am passionate for.

To Adrian van Eyndhoven for helping me and guiding me during the process, providing indispensable advices and information.

To the Bosch engineers and the research team for taking their time to grant me with useful information.

To the Faculdade de Arquitectura da Universidade de Lisboa and specially to Carlos Oliveira Santos, your help in every aspect of this journey was essential to complete this Final Project Work. Thanks for guiding me in the right direction.

Special thanks to the farmers that provided this work with rich information. Without them, this Final Project Work would not have been the same.

And I would like to express my thanks to my lovely and supportive family, parents and sisters, as well as to my friend Angela.

Finally, and most important, to Nicolai Novinc who has been my biggest support. Thank you for your patience, for sharing your knowledge with me, and for caring me unconditionally.

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LIST OF ABBREVIATIONS

App - software application

HCD - human-centered design

IoT - Internet of Things

PA - precision agriculture

SF- smart farming

UX - user experience

GLOSSARY

Big Data	- Extremely large data sets that may be analysed computationally to reveal patterns, trends, and associations, especially relating to human behaviour and interactions.
Blüba	- Garden planting company in Germany
Cloud	- A network of remote servers hosted on the Internet and used to store, manage, and process data in place of local servers or personal computers.
Device	- An object or machine that has been invented to fulfil a particular purpose.
Fleece	- The woolly covering of plants, fibres, etc., used to protect.
Gestalt	- German expression for shape, figure or form.
Internet of Things	- The interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data.
Sensor	- A device which detects or measures a physical property and records, indicates, or otherwise responds to it.
Smart devices	- Electronic devices that are normally connected to other devices or networks via different wireless means, being able to share and interact with its user and other smart devices.
Stakeholders	- A person such as an employee, customer, or citizen who is involved with an organization, society, etc. and therefore has responsibilities towards it and an interest in its success.

See Oxford Advanced Learner's Dictionary (7th edition, 2005);
and Cambridge Advanced Learner's Dictionary (4th edition, 2013)

FOREWORD

Smart devices have been gaining more space and relevance in our lives. Smart homes are an example of it: smart hubs, i.e., act as a core element by connecting all products. Thus, users can control lighting, temperature and turn on/off other devices remotely (see Porter and Heppelmann, 2014). They exist to make our lives easier. However, there is a tenuous line between intelligent devices that really improve our life quality and smart devices that make in fact our life more complicated (see Norman, 2013). This new era gives new perspectives on how products can be designed, and designers have the power to create meaningful experiences, rather than just things, by stepping into the users' world right at the beginning of the design process (see Suri, 2003; Chhatpar, 2007).

After a thorough research with farmers and stakeholders, the company Bosch has developed a sensor device that is able to monitor the soil temperature to ensure farmers to keep it at an optimum for asparagus growth (temperature can be controlled with the use of a cover that have two colours, one black and one white side). The sensors are placed inside the device, which in turn is placed on the soil and it collects data as temperature and humidity. The data is stored in a cloud system and helps the farmer to improve the harvest of asparagus and avoid crop loss that is associated with factors such as excessive or insufficient heat or cold and improper atmosphere. After successfully being introduced in the market, Bosch carried a second research with the aim of identifying farmers' needs in the strawberry sector. The outcome was the foundation for this Final Project Work: farmers want a sensor device indeed, but one that can adapt to many crops.

Each crop requires different care approaches, i.e., the soil humidity is not interesting for asparagus, while for raspberries it is. The challenge thus, was to create a singular sensor device that can adapt to each farmer's crop by considering relevant information collected in the fields. In order to achieve this, the designer was immersed in the farmers' context by embracing a human-centered approach through the whole process.

CHAPTER ONE

A USER-CENTERED DEVICE DESIGNED FOR SMART FARMING

1 Problem statement

The Internet of Things (IoT) is growing rapidly and it reflects the rise in the number of intelligent and connected devices (see Verizon, 2016). People are gradually embracing smart devices, but many factors still impede a mass adoption of such technology (see Accenture, 2014a). People are thwarted with modern devices because, among other reasons, they appear to be difficult to use and the data collection make consumers feel unsafe (see Accenture, 2015a). These devices use indeed high technology and are therefore also complex to be designed; however, designers are able to overcome users' issues towards a product by incorporating a user experience (UX) approach (see Norman, 2013). Designers need to go beyond ergonomic and functional aspects and focus also on the users' emotions, goals, aspirations, motivations and values. Bosch Deepfield Connect was created based on the users' needs and the product's easy look gained the confidence of the farmers. Likewise, Gartner, the world's leading information technology research company, believes that a successful product "must appear simple and usable for non-technical individuals" (see Gartner, 2014).

2 Research questions

Considering that the creation of technological complex devices is a challenge, seven questions were raised and answered in the course of this Final Project Work:

How designers can overcome design quality issues?

Why sensor technology is important for agriculture?

What are the farmers' needs towards sensor devices?

Why people are reluctant of buying smart devices?

How to address the users' needs on modern devices?

What both researches carried by Bosch provide for this Final Project Work?

How a human-centered design (HCD) approach can help on the development of successful devices?

3 Question zero

Design and research projects at Bosch always start with the statement of the main question that should be answered at the end of the project. The Question zero should guide the designer through the process, but does not necessarily remain the same, as the designer constantly receives more and more information and is therefore able to sharpen its knowledge about the subject and consequently rephrase the question. At the beginning of the design process the initial question was:

How a universal agricultural sensor device should be designed in order to satisfy the current farmer's needs?

The Question zero was later rephrased as it became clear how important is to consider the entire experience for the development of a product:

How an agricultural sensor device should be designed, by addressing the farmers' needs, in order to provide them a pleasant interaction?

4 Objectives

4.1 Main objective

On the basis of Bosch research, the main objective of this Final Project Work was to study the creation and development of a sensor device concept for agriculture based on the users' needs. Although the device's complexity, the main characteristic of the product must be to look simple and reliable in order to gain the confidence of the user.

4.2 Specific objectives

- Study the researches already made by Bosch and identify specific farmers' preferences towards sensor devices
- Research theory about agriculture, sensor technology and the trend of smart devices
- Apply human-centered design methods during the process
- Create a concept for a sensor device that meets the user's needs
- Verify which kind of technology is suitable for developing the product (materials and production)

5 Design goal

Design a universal sensor device for agriculture that support farmers' decisions in order to optimize the agricultural production.

CHAPTER TWO

A THEORETICAL FRAMEWORK

1 AGRICULTURE: A QUICK GLANCE AT THE HISTORY

2 PRECISION AGRICULTURE

3 INTERNET OF THINGS

4 SMART FARMING

5 ACCEPTANCE PROBLEM

6 ROLE OF DESIGNERS IN DESIGNING MODERN DEVICES

1 Agriculture: a quick glance at the history

The domestication of plants and animals dates back 10,000 years and many theories attempt to explain why and how the transition from foraging to farming occurred (see Weisdorf, 2005). This transition has been frequently referred to as the Neolithic Revolution and had impact on many aspects of human life, such as economic, technical and cultural (see Mazoyer and Roudart, 2006). It was a gradual and independent process in which techniques and domestication were not developed rapidly and simultaneously, but it lasted 1,000 years to complete its maturation (see Diamond, 1997). Considering that the emergence of agriculture is the result of a progressive evolution, there was a lack of knowledge on how to practice agriculture; on the other hand, humans were free to create different systems of food production and animal breeding, as well as innovative tools and techniques to enhance their agrarian productivity (see Mazoyer and Roudart, 2006).

Agriculture changed living conditions and increased labour supply, i.e. production of implements for agriculture, enabling the technological and science progress (see Martin and Sauerborn, 2013). With the following agricultural revolutions, motorization and mechanization, it was possible to increase food production in order to attend the increase number of people. Today, there are at least 570 million farms around the world (see FAO, 2014); nevertheless, the demand for food needs to grow by 70% until 2050, as a result of population growth (see FAO, 2009). With the forecasted expand from 7.2 billion to 9 billion people (see Gartner, 2015), agriculture needs to respond by changing their patterns of production, storage, process, distribution and access (see Godfray *et al*., 2010). One way to face this challenge is to apply Precision Agriculture (PA) principles and use the new connected technology, as smart devices that are capable to “sense” the environment and collect data that humans cannot (see Ashton, 2009).

2 Precision agriculture

The National Research Council (1997, p.2) defines PA as “a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production”, and attributes three aspects of PA: (1) collection of data in a determined frequency, (2) interpretation and analysis of that data and (3) a management response to that analysis. In order to achieve a precise management, the farmer needs to understand the crop requirements and this requires technology information from the fields (see National Research Council, 1997). Today, there is a great variety of technologies, methods and equipment, e.g. remote sensing, GPS, yield monitoring, and soil sampling techniques that support the collection of necessary information. Moreover, the goal of PA is not to replace the farmer expertise, but rather provide them with correct information in order to support onfarm decision-making. As a result of a better management, efficiency, productivity and profitability can be increased (see Beechman Research, 2014).

Although PA has become more popular recently with the development of sensor technologies, it is not a modern concept. In fact, this concept have been practiced by farmers since early time when they divided the fields into smaller areas in order to grow the crops according to the characteristics of each soil (see Oliver, Bishop and Marchant, 2013). However, until recently, PA relied fundamentally on data from individual sensors (see Griepentrog, 2011) and, as envisioned by The National Research Council (1997, p.12), “Precision Agriculture will probably evolve as a combination of services and products”. The trend today is to connect all equipment with the help of the Internet of Things, in order to create an intelligent ecosystem and, thus, improve even more the productivity. The principal analyst at Beecham Research, Saverio Romeo states that the IoT will be the major driver for agriculture to move towards an intelligent farm (see Beecham Research, 2016).

3 Internet of Things

The term Internet of Things was first used by Kevin Ashton (see Sundmaeker *et al.*, 2010). Accenture (2015b, p.2) defines IoT as a “universe of intelligent products, processes and services that communicate with each other and with people over the Internet”. It is an era in which everything becomes connected and interactive at anytime and anywhere (see Sundmaeker *et al.*, 2010) and it is changing the way people and industry live and work (see Accenture, 2014b). The capacity of sense and communicate is possible due to sophisticated sensors that are embedded in physical things, making it possible to collect and exchange data with each other, turning those “ordinary” devices into intelligent ones. The amount of data collected, known as Big Data, is transmitted to a cloud that in turn use analytics to share the most relevant data according to specific needs (see IBM, 2015).

Hence, intelligent objects are able to recognize events in their environment and respond autonomously in an appropriate way (see European Union, 2014). One example is the Nest Thermostat from Google, which is not just another “normal” thermostat because has sensors inside that learn your heating patterns and is able to create a schedule that will, e.g., turn off the heating when the person is not at home or will be capable of calculating how long it will take to get the house up to temperature at the right time (see Gibbs, 2016). Besides, Nest Thermostat can also communicate with other products from Google, such as Nestcam or Nest Protect smoke-detector; and this is what the IoT is all about: to create an ecosystem of objects that are able to communicate with one another, and learn from each other in order to become smarter and, thus, work more efficiently (see Vermesan and Friess, 2013).

According to Accenture (2015a), this network of connections introduce the era of “digital ecosystems”, where companies will work together so they can provide people with a richer experience. However, there is still a competition mind-set between the companies that prefer the dominance of the market over a cooperation, which prejudice the diffusion of smart products (see Pierce, 2015; Newman, 2015). Nevertheless, this digital revolution is currently happening and, according to Gartner (2015), there are already 5.5 million of devices connected today, and the tendency is to have 20.8 billion of smart devices by 2020.

4 Smart farming

With the rise of smart cars, smart homes and smart consumer products, people are getting familiar with the term “smart”. However, the application of intelligent systems is not limited to consumer products. Industry is also embracing this transformation towards the next industrial revolution, the so called Industry 4.0, and by doing so, they are able to reduce costs and increase efficiency (see Accenture, 2016). Companies as Monsanto and DuPont are already using Big Data to improve the yield of crops. Already in 2014, Monsanto believed that providing farmers with advices from data collected in the fields would reduce input costs and increase yields by 20 million USD a year (see Bunge, 2014). Farms that connect machinery, devices, animals and crops in order to collect data and use this information to improve production are called Smart Farms (see AIOTI, 2015) and have the power to attend the greater demand for food (see Fedoroff, 2015; Foley, 2014). Farms are slowly embracing the Smart Farming (SF) concept, however, there are many aspects that can hamper the adoption of such technologies (see Tey and Brindal, 2012).

5 Acceptance problem

In the era of smart cities and smart homes, life becomes easier: objects are connected, communicate with one another and can be controlled from anywhere, enhancing consumers' comfort and convenience (see The Consumer Goods Forum, Capgemini and Intel, 2016). The concept might work well if someone wants to turn on the dishwasher while at work or adjust the room temperature before arriving home. However, the result from both researches made by Bosch (Bosch, 2014; Bosch 2015a) showed that farmers are reluctant about managing their farms through their smartphone. The fear is reasonable, as many articles write about how convenient is to control your life through your smartphone (see Kobie, 2015; GSMA, 2015; Pierce, 2015). Another insight gained during the researches is that farmers do not want to get "instructions" on how to deal with their crops, but rather get advices based on information that farmers do not have knowledge about. In addition, the quantity and complexity of data that can be gained from the fields is very high and as Kevin Ashton (2009, online journal) says, people "are not very good at capturing data about things in the real world".

Thus, if smart sensor technology aims to help farmers, then why there is a problem with the acceptance of such technologies? In reality, there are many factors that can affect the acceptance of precision farming technologies, such as "cultural perception, lack of local technical expertise, infrastructure and institutional constraints, knowledge and technical gaps and high start-up costs with in some cases a risk of insufficient return on the investment" (see European Union, 2014, p.43). Furthermore, in the research made by Bosch, many farmers had no information about sensor devices in agricultural fields and/or had no experience with sensors so far. It was also mentioned that the relevance of sensors is unclear, exists a fear of investing in such technologies, and when such a sensor technology is purchased, they don't use it due to its complexity. Thus, there are many challenges that need to be faced in order to gain the farmers' confidence toward smart products.

First, the lack of knowledge about SF concept needs to be surpassed. Smart Things are more related to a driverless car or a smart thermostat, and consequently the term smart farming is strongly related to a farm controlled by technology rather than a concept based on precision agriculture principles. These principles match the desire of farmers: get information through technologies in order to improve their management (see National Council Research, 1997; McBratney *et al.*, 2005; Oliver, Bishop and Marchant, 2013). Thus, SF is "strongly related" to PA (AIOTI, 2015, p.4), the difference is that SF is supported by IoT to connect everything in order to create an intelligent ecosystem, something that, until recently, PA did not manage to do (see Griepentrog, 2011). Although many articles describe SF and PA as the same, for this Final Project Work, SF is the term that shall be used to describe the use of a connected ecosystem that relies on the principles of PA.

Another factor mentioned in the interviews carried by Bosch (Bosch, 2014; Bosch 2015a), was the complexity of high tech devices. Accenture's research (2014c) also pointed the same problem: many customers think smart devices are either "too complicated to use", "set-up did not proceed properly" or "did not work as advertised". As high technological devices, they need to express other values that goes beyond its complexity. As Norman (2013, p.3) mentions, "two of the most important characteristics of good design are discoverability and understanding"; users need to be able to identify what are the functions of the product and how to use it. A smart device does not have to look complex just because its high technology, moreover, such a device needs to be designed considering who is going to use it (see Kimmel, 2015), and therefore researches and designers come into play by identifying the users' needs and respecting them since the front-end of the design process.

6 Role of designers in designing modern devices

What is actually a good design? Besides filling ergonomics, engineering and manufacturing requirements, designers need to ensure that the user can use and understand the product, and if possible, enjoy the whole experience (see Norman, 2013). Experiences itself can vary from person to person, as everyone interacts with a product differently, either because of personal, social or culture factors (see Suri, 2003; Kimmel, 2015).

Today, designers have the opportunity to appropriately influence those experiences by truly understanding design elements and their phenomenon. When not focusing simply on functions, but on the whole activity that involves the product, designers can "shape and support people's experiences in intended and desirable ways" (Suri, 2003, p.41).

However, it is not possible to control nor design people's personal experiences, but it is possible to trigger it by changing aesthetics and interaction qualities. Designers need to focus on attributes that they can change, e.g. "formal sensory qualities, sound, smell, mass and texture and behavioural qualities, feedback, rhythm, sequence, layering and logic" (idem, p. 41). In order to be able to design these formal and behavioural qualities, designers need to have a thorough understanding of what is important for the people they are designing for, as well as their needs and motivations.

For Norman (2013), a good design is the ability of understanding psychological and technological aspects, as well as providing a high interaction quality between the user and the machine. One way to understand all factors that influence a good design is by embracing a human-centered design (HCD) approach, and by doing so a product will not only fill its functionality, but also evoke strong positive emotions through the entire experience. HCD helps designers to gather a thorough understanding of peoples' motivations, emotions, feelings, values, preferences and inner conflicts, so the designer can gain empathy for whom he is designing. Many authors agree that empathic design is the key for innovative solutions (see Leonard and Rayport, 1997; Black, 1998; Battarbee *et al.*, 2013). Moreover, researches and designers have the ability to transform objective data into sensitive deductions, creating an empathic bond with the user, and, by doing so, it increases their capacity of receiving and processing the information (see Battarbee *et al.*, 2013). The research succinctly described below, drew on a HCD approach to identify potentially critical farmer needs, and provided this Final Project Work with a solid grounding for the development of a tangible design concept for agriculture.

CHAPTER THREE
METHOD

1 The user centered approach

Following Bosch research, it was adopted an HCD method to developed a own research, which means that we have included ourselves in that large user-centered design zone, as defined by Sanders (2006; 2008), including approaches like contextual inquiry (Beyer and Holtzblatt, 1997), human factors and ergonomics (Dreyfuss, 1955), lead-user innovation (von Hippel, 1988, and 2005), applied ethnography (Rothstein, 1999), and usability testing. All this zone is not far away from the co-creation zone, involving participatory approaches, including the Scandinavian methods (Greenbaum and Kyng, 1991) and the generative tools approaches (Sanders, 2000; Sleeswijk Visser, Stappers, van der Lugt and Sanders, 2005; Sanders and Stappers, 2014).

Under the influence of these zones, this specific HCD approach was focused on the needs of potential end-users, assessed in the design product development process, and considered very important for achieving the company's strategic and innovation goals.

Over the past years, the design practice has been changing in every aspect of its field, and it is gradually being seen as a strong strategy inside companies. As a result of those new approaches and methods emerging in the design discipline, the role of designers have changed to a profession that adds value to a company by its harmonious and dynamic way of working. Sanders and Stappers (2014, p.26) define this change as a shift "from designing for people to designing with people and by people". Designing by exploring and understanding users' needs was a great step for designers. They were already considering users' specifications, but still not the whole experience resulted from what was designed.

Nevertheless, this mindset of designing for people was a big step towards designing together with people, as it became increasingly clear that the users are, in reality, experts. This transition resulted in users being considered not only at the beginning of the development process, but also along the whole project. Moreover, an interdisciplinary mindset followed this transition and now, design teams also include different disciplines within the design process. Bosch has been implementing a creative thinking approach in their environment as a way of boosting creativity from not only designers but also from all disciplines. Project teams at the company are now composed of product designers, researchers, engineers, advertisers, graphic and interaction designers and managers. This new mindset ensures employees to collaborate and engage with one another, and consequently not see their disciplines as separate segment anymore.

2 A multitrack interdisciplinary model for design development

For this specific research experience, it was very important to be aware of Chhatpar (2007) approach. Traditionally, design intervention or even user validation followed the definition of a business strategy, as independent and sequential components (Figure 1).

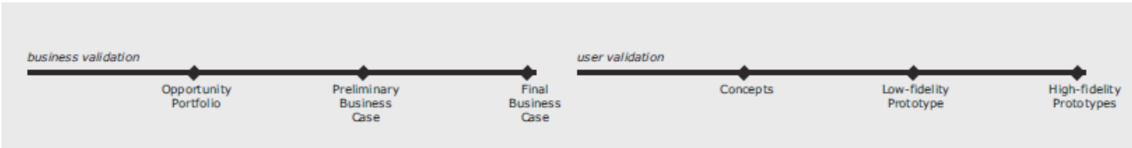


Figure 1 - Traditional approach of business, design and user validation (Chhatpar, 2007)

For Chhatpar (2007, p. 31), “to succeed in today’s market, businesses must instead adopt a new view of decision-making”, consisting in “a coordination of roles across an organization to support broad, less-bounded strategic approaches that permit action in a more responsive way”. According to this new enhanced approach, business need to run, since the beginning, in a multitrack interdisciplinary process with design research and users participation (Figure 2), in which design research activities bridge the tracks and improve the output of both business and users validations.

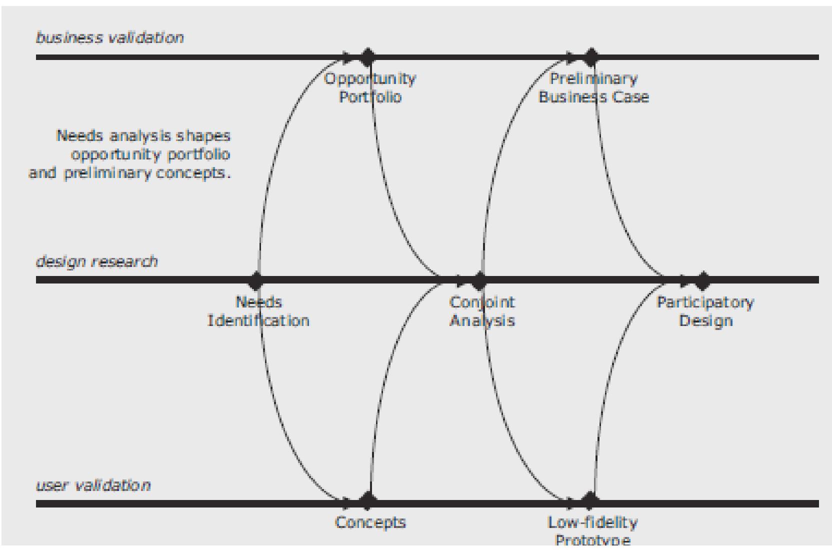


Figure 2 - New approach (Chhatpar, 2007)

This new approach includes designers and users actively during the whole process, by providing concepts and tools since the beginning, the so-called “fuzzy-front-end” (Sanders, 2013, p. 65). Between needs identification and participatory design (Figure 2), we can develop three categories of tools: Say (e.g. interviews); Do (e.g. observations); and Make (e.g. prototyping). The category “Make” provides the team with a deeper level of understanding, since the users are able to perform their imagination by creating something (see Sanders and Stappers, 2014).

By making things, people are able to express better what they wish, and designers can therefore construct prototypes that meet better their expectations. The use of prototyping is one of the techniques to carry usability testing during the design process. User testing helps to validate concepts and gather quickly feedback from users, i.e., “employs a broad range of techniques designed to measure a product’s ability to satisfy the needs of the end user” (O’Grady and O’Grady, 2009, p. 52).

Bosch is employing an approach that uses this participatory design and includes different disciplines that were constantly overlapping during the whole process. This new approach provides the company with concrete information to make better decisions. This Final Project Work drew on this approach to make the final design concept for farmers, and Bosch will make use of the results and keep evaluating with all disciplines and users, in order to validate the best option before bringing it to the market.

3 Research framework

According to these methodological fundaments, here is the generic framework of this research (Table 1):

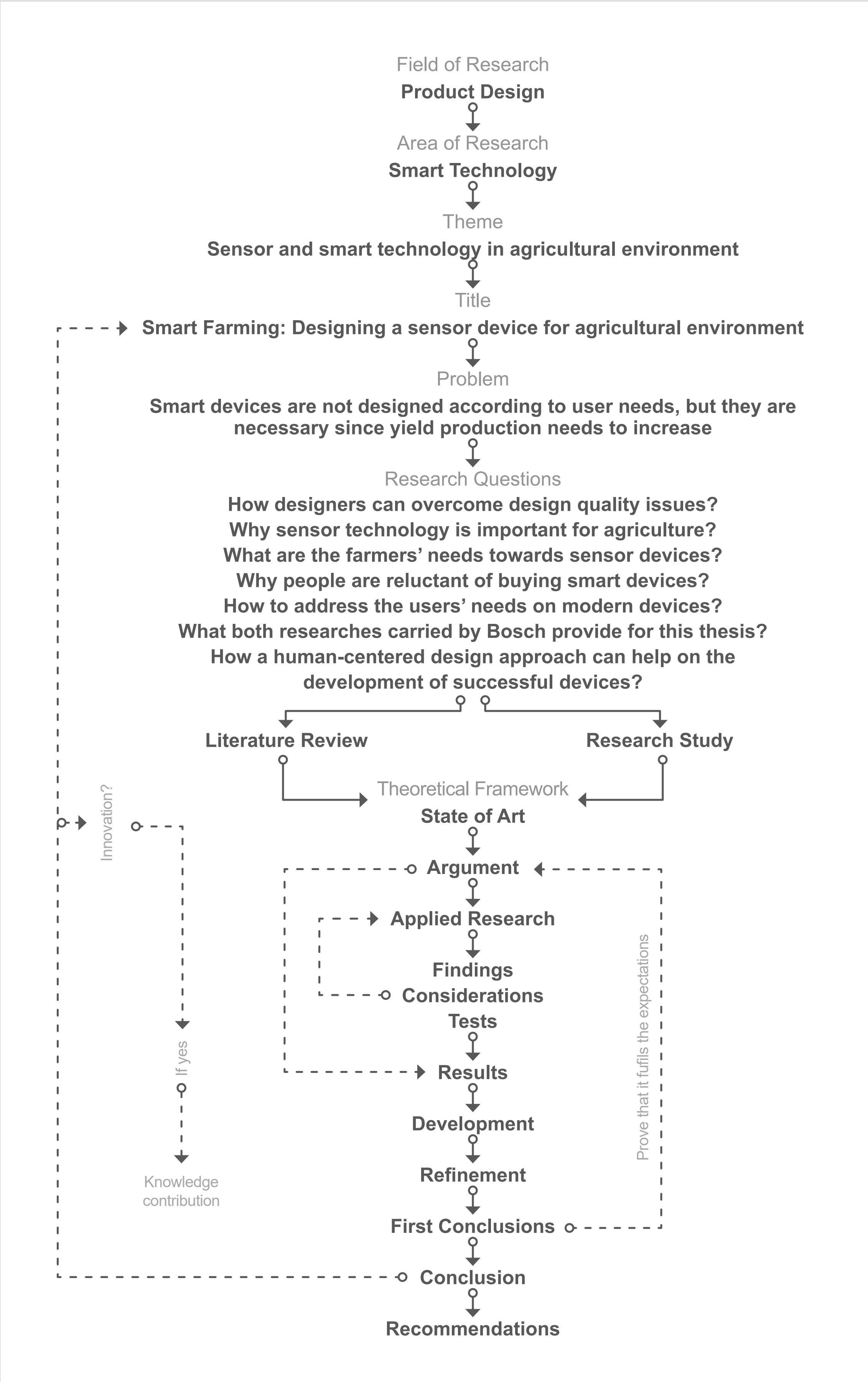


Table 1 - Research framework

CHAPTER FOUR
FIELD RESEARCH

*Note: This chapter contains some images with German texts.
These texts are not relevant and were therefore deliberately not translated.*

1 Bosch studies

The Asparagus and Strawberry studies gathered valuable information and provided with their results a crucial foundation for this Final Project Work. Therefore, it is of great importance to describe succinctly both studies and their outcomes, as they enlivened the present study.

2 Asparagus research

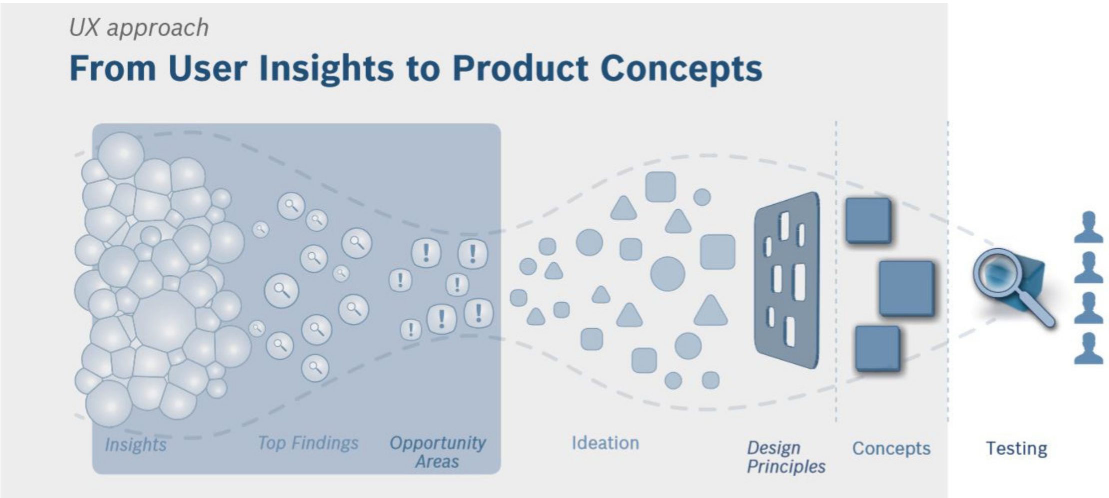


Figure 3 - Bosch Design Process (Bosch, 2014)

2.1 Research process

With the objective of creating functional concepts of a modular agriculture robot in the asparagus fields, Bosch carried in Germany, 2014, sixteen exploitative interviews and in-context observations. Involved in the research were: ten farmers with different cultivations, one greenkeeper, one manager parks commission, one manager of „BlüBa" (a garden events company), one forest manager, one manager of a tree nursery company, and one cultivation consultant as expert (Figure 3). For the conversation with the users, the team used the farmers' journey (Figure 4) as a framework.

After the relevant pain points and perspectives were identified, a tour around the farm and the fields was made in order to collect insights about machines, working procedures and current activities (Figures 5). The field research led to the discovery of statements as:

Farmers wish to have machine processing, better logistics, intelligent supply, better environment conditions, monitoring, supervision and reducing of paperwork.

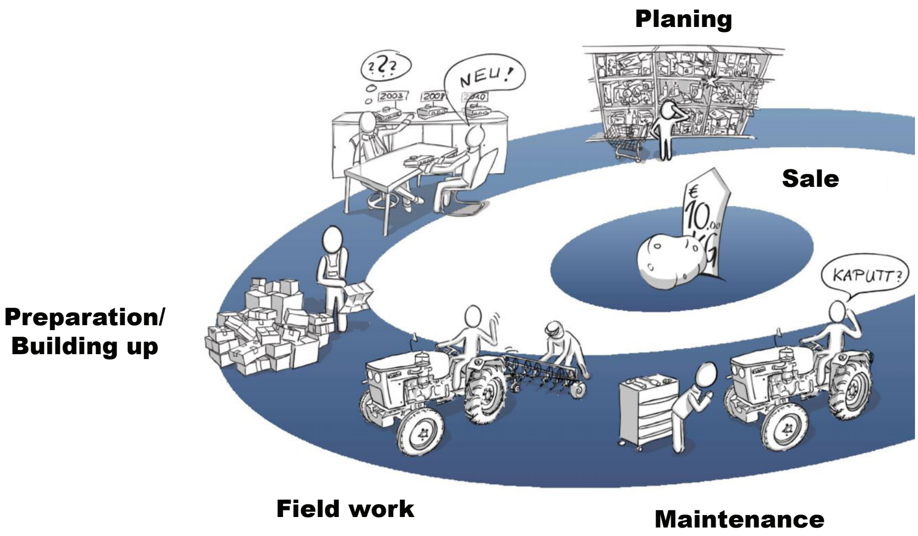


Figure 4 - Farmers‘ journey (Bosch, 2014)

Figures 5 - Observations and tour around the farm (Bosch, 2014)

Furthermore, the team was able to identify many relevant insights, that were later narrowed to eighteen top insights to consider in the next phase:

1 – Farmers secret diary
2 – Act on (market) request
3 – Context-based efficient farming
4 – Irreplaceable manual work
5 – Farmers do it themselves
6 – Need for proper legibility
7 – Pleasure and pain of tractor riding
8 – Misleading assumptions
9 – Pain point staffing
10 – Sharing and Cooperating is unavoidable
11 – Test to explore
12 – Dealing with God-given circumstances
13 – The strategic farmer
14 – Interferences are daily business
15 – Relying on well educated guess
16 – There is nothing like practical experience
17 – Stay tuned with evangelists
18 – Ad-hoc workflow

Some observations were also important to consider further: **farmers are inquisitive about new technologies, types of crops and cropping strategies, they love to explore and test new products.** Thereupon, Bosch carried creative sessions (Figure 6) based on the findings in order to identify opportunity areas and design principles, and also defines the opportunity areas (what?) as spaces for possible solutions and design principles as (how?) the solution will be perceived.

Figure 6 - Creative session at Bosch (Bosch, 2014)

Opportunity areas identified
Build up crowd-farming • Flatten out peak times • Expose the hidden potential • Be a transfarmer • Complement with credible propositions • Foster meaningful tinkering • Transfer data into knowledge • Lift the curtain and Keep the spark
Design Principles
From lab equipment to fit for the field • From skeptical distance to mutual trust • From a unicorn to a workhorse • From programmed execution to supportive cooperation • From forceful intervention to considerate handling

Table 2 - Asparagus opportunity areas and design principles

Bosch carried ideation workshops (Figures 7) to create first and rough ideas based on the previous findings and later narrowed to three concepts that were then presented to farmers and stakeholders in form of rough prototypes and a storytelling. The storytelling had the aim to help farmers to dive into the idea and understand how the concept would work in a daily situation. The aim of presenting concepts was to get feedback regarding potential and practicality and also to gain an impression about general openness of farmers towards futuristic ideas. The concepts were evaluated based on general liking and personal benefit and were then ranked and rated according to its potential.

Figures 7 - Ideation Workshop at Bosch (Bosch, 2014)

2.2 Concept Scout

- An autonomous drone taking pictures of the field's condition while flying over
- Yielding of integrated field sensors provides direct contact to the field in order to investigate the condition of soil and crops;
- Mountable black-box allows to track the machine use;
- Scout Platform for collecting data of the field.

Figure 8 - Concept Scout visualization (Bosch, 2014)

Based on the feedback, for every concept a SWOT analysis was made:

SWOT analysis

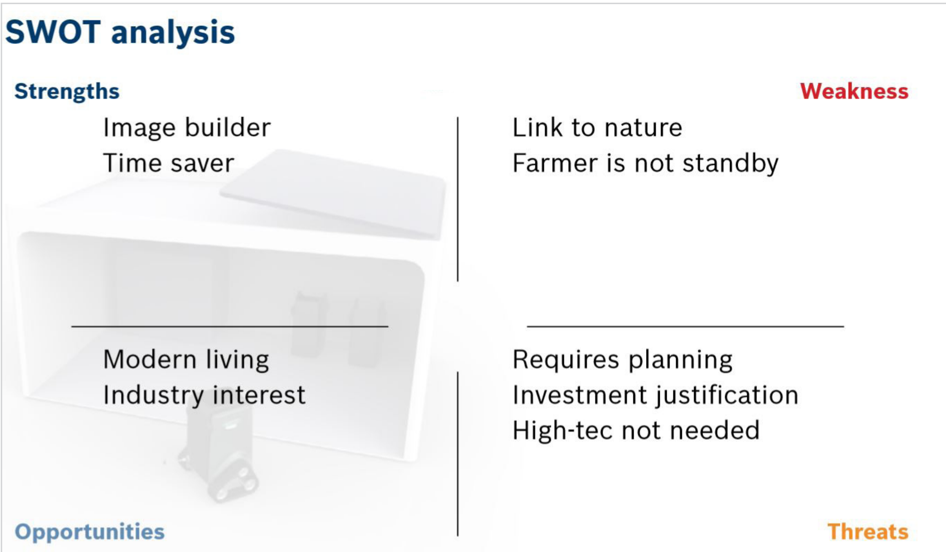
Strengths	Weakness
Universal Independent Objective Automated documentation 24/7	Lack of countermeasures
Opportunities	**Threats**
Extendible Adaptable Package sale Different motions	Trusted data handling Farmers know-how Skeptisism Cost Data translation

Table 3 - Concept Scout analysis (Bosch, 2014)

2.3 Concept My Yield

- Energy self-sufficient all-round robot, driving and acting autonomously
- Supports the cultivation of small fields
- Offers tips regarding upcoming works and serves as transport equipment for tools
- Sends status and predictions directly from field to “Grünfutter” app

Figure 9 - Concept My Yield visualization (Bosch, 2014)



SWOT analysis

Strengths	Weakness
Image builder Time saver	Link to nature Farmer is not standby
Modern living Industry interest	Requires planning Investment justification High-tec not needed
Opportunities	Threats

Table 4 - Concept My Yield analysis (Bosch, 2014)

2.4 Concept Lego

- Modular autonomous agricultural robot – adaptable through easy rebuilding by the farmer
- A basis is equipped with functions by adding further components for completing very particular as well as sequential tasks
- As a competent partner, Bosch offers services online and on-site

Figure 10 - Concept Lego visualization (Bosch, 2014)

SWOT analysis

Strengths	Weakness
Flexible Autonomous 24/7 Combine functions Adaptable	Too modular Modern tractor is smart Know-how needed Chain failure
Opportunities	**Threats**
Simplicity must Expansion platform Works independent Semi independent	Failed if complex Feasibility doubts Little differentiator Legal Misses use case Investment paradox

Table 5 - Concept Lego analysis (Bosch, 2014)

Figures 11 - Concept Testing with stakeholders (Bosch, 2014)

Based on the SWOT Analysis the team built a graphic to help visualize the overall ranking, where is possible to see that the concept Scout had the highest preference among the others.

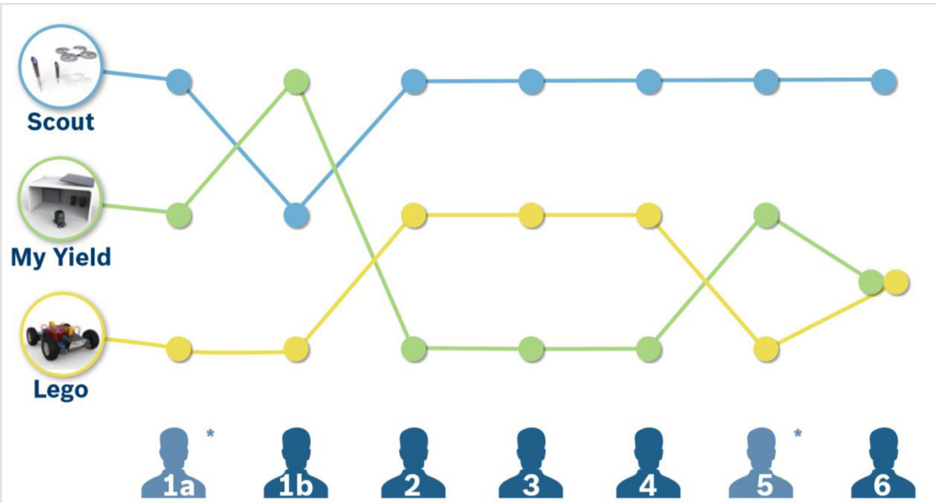


Table 6 - Concept Comparison (Bosch, 2014)

The results led to the following conclusions:

Scout - Concept with highest potential and closest to the market; automated sensing and documentation is seen as very beneficial; data must be handled with care.

Lego - Farmers doubt the concept's simplicity; technical solution of the concept principle not understood (or perhaps not well presented); suitable for small and diverse farms that don't have the money; only advantage is seen in the autonomous driving and working functionalities.

My Yield - Farmers do not see a market for this concept; better concentrate on a small and autonomous field robot specialist, e.g. for weed control.

Based on the results that the Scout concept has future potential, Bosch developed further a sensor device and a connected app to support the service/product. The result was the development of the *Bosch Deepfield Connect* (Figure 2), a sensor device for asparagus that measures the ground temperature using a high precision temperature sensor. The sensor device is placed on the soil and measures every hour the temperature. A gateway box, which contains aerials and is connected with a cable to the device, sends via Internet (GSM) all values to Bosch Cloud, which in turn sends all the information to the connected app. With the data, the farmer can decide how best to proceed.

The product was introduced in the market in 2015 and due to its success, Bosch decided to work further on the agricultural sector.

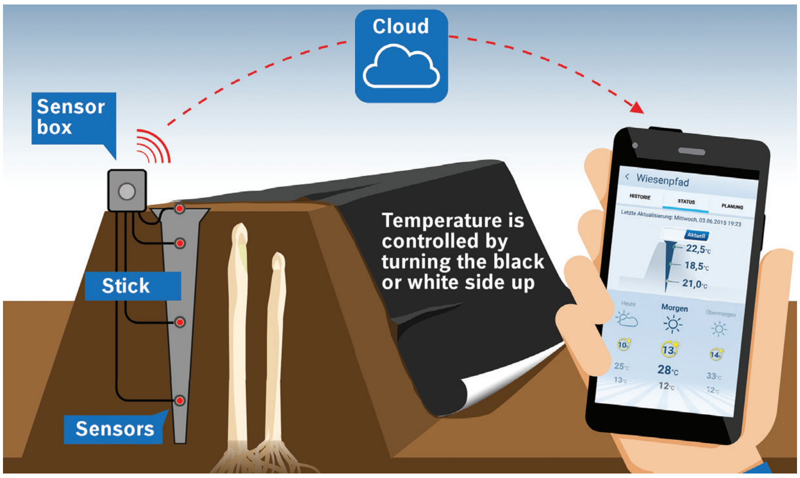


Figure 12 - Bosch Deepfield Connect - How it works (Bosch, 2015)

Figures 13 - Bosch Deepfield Connect (Bosch, 2015)

3 Strawberry research

3.1 Research process

The following project realized by Bosch had the aim to create functional concepts of a modular agriculture solution that simplifies operations and processes. The goal of the user research was: to gain user insights about the challenges in agricultural business with focus on strawberries; identify user needs towards sensors; focusing on strawberries under foil and tunnel (Figure 14); and identify further user insights and needs concerning other fruits under foil or other agricultural aspects.

Figure 14 - Strawberries inside the tunnel (Bosch, 2015)

In August 2015, Bosch carried eight explorative interviews with farmers focusing in the strawberries cultivation in tunnels. The approach was to conduct semi-structured and face-to-face interviews that lasted ca. 90 minutes. The interview guideline comprised the following sections:

• Introduction to project & team;

• Questions about the farmer's demographics & farm;

• Questions about working procedures on strawberries under foil/ tunnel;

• Questions about sensors in the field of strawberries under foil/ tunnel;

• Experience Studies & Wrap-Up.

After the interview, the team made a tour around the farm and the fields to collect further insights and get a visual illustration and explanation directly at the working site:

Figures 15 - Observations and tour around the farms (Bosch, 2015)

With rich information gained during the field research, the team created an overview of what happens during a year in the agricultural fields:

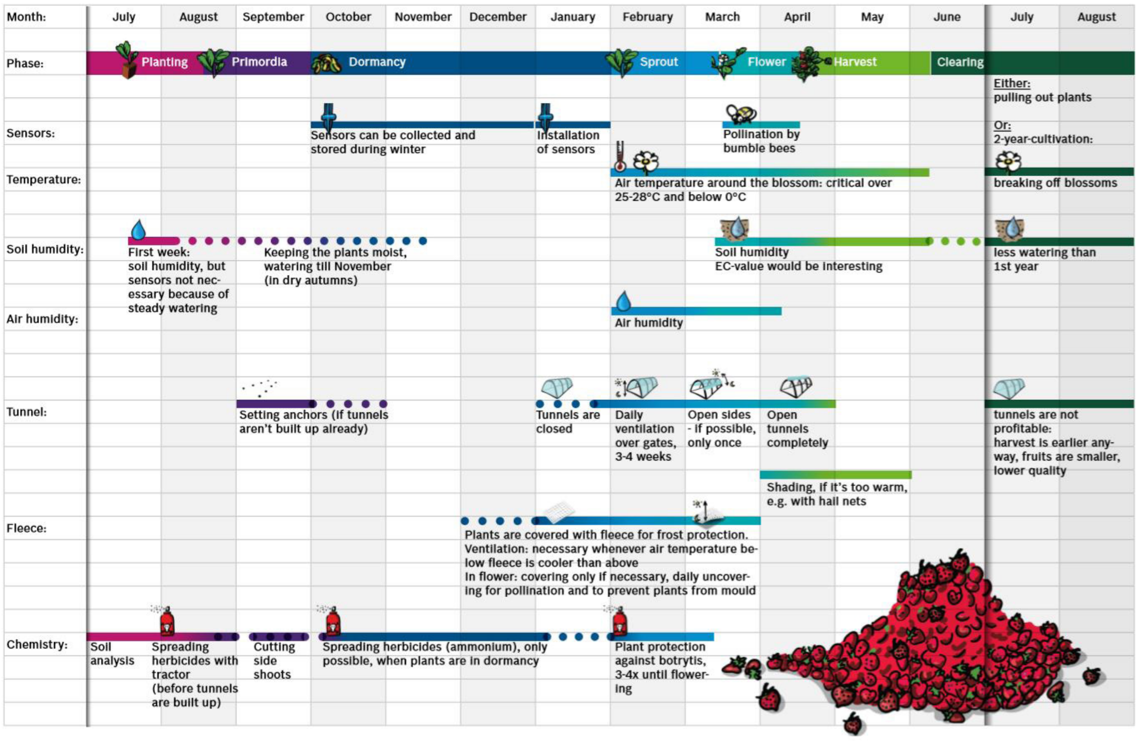


Table 7 - Strawberries in a year (Bosch, 2015)

Since the crop care inside tunnels were very relevant in this research, a detailed overview of how the procedure is operated is displayed below. It is important to note that the fleece plays an important role during the crop care, since it protects plants against frost, wind, hail, birds and insects.

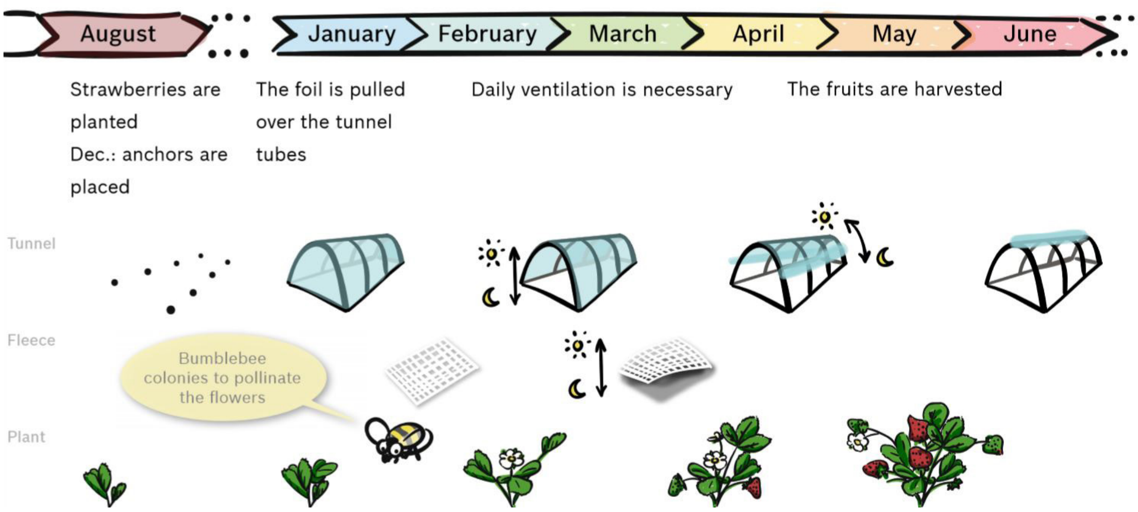


Figure 16 - Working procedure inside tunnels (Bosch, 2015)

As in the previous research, creative workshop sessions (Figure 17) took place in order to organize all the insights collected and identify the opportunity areas. The insights gained during the interview and observations are very extensive and some do not have directly influence on this Final Project Work (i.e., strawberries related), so they will not be mentioned.

Figure 17 - Workshop Creative Session at Bosch (Bosch, 2015)

Nonetheless, during the sessions, the most relevant insight identified was that users indeed **need sensors**. Therefore, the team collected information directed specifically at sensors. The following images provided by Bosch explain which sensors are interesting for farmers, where they should be placed, how the measurement should be done, hardware requirements and general reliability on such a technology:

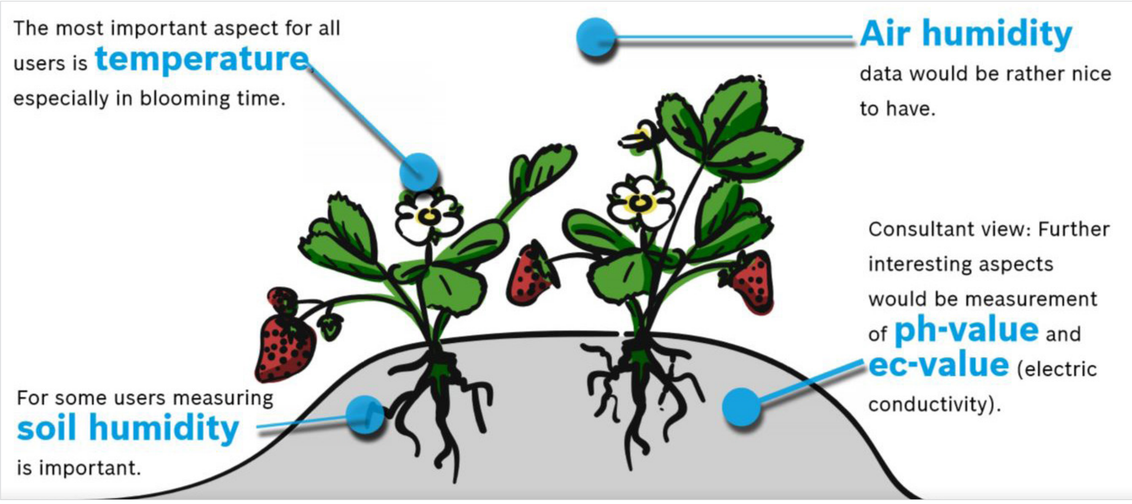


Figure 18 - What sensors are interesting (Bosch, 2015)

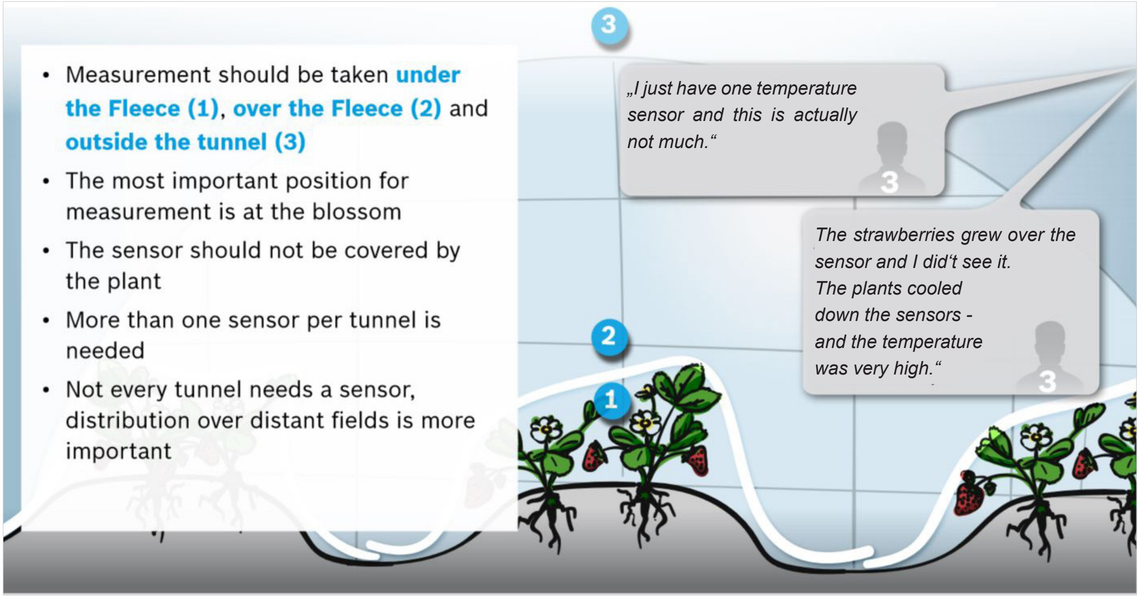


Figure 19 - Where sensors should be place (Bosch, 2015)

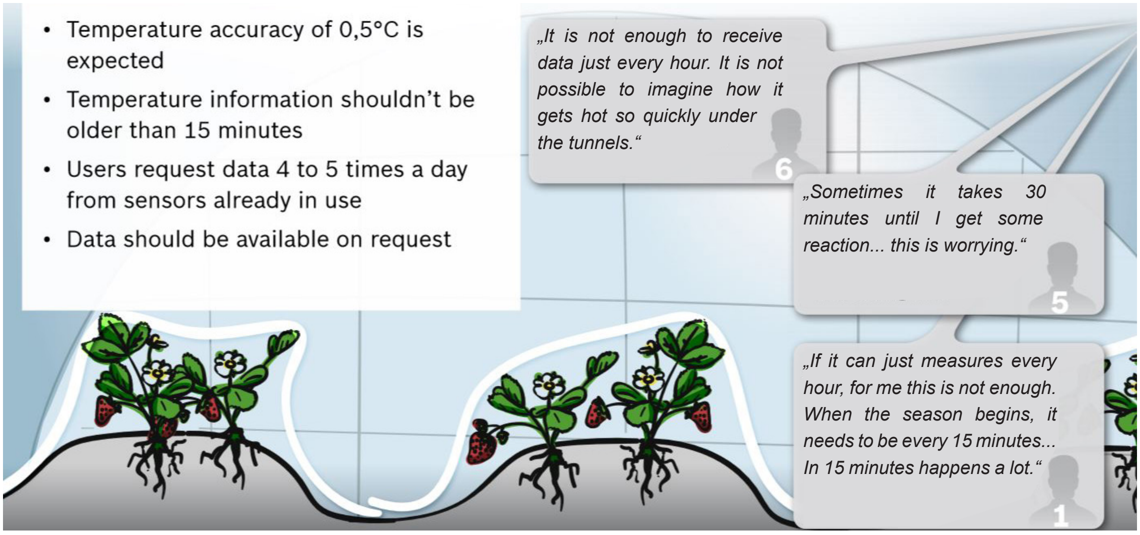


Figure 20 - How the measurement should be made (Bosch, 2015)

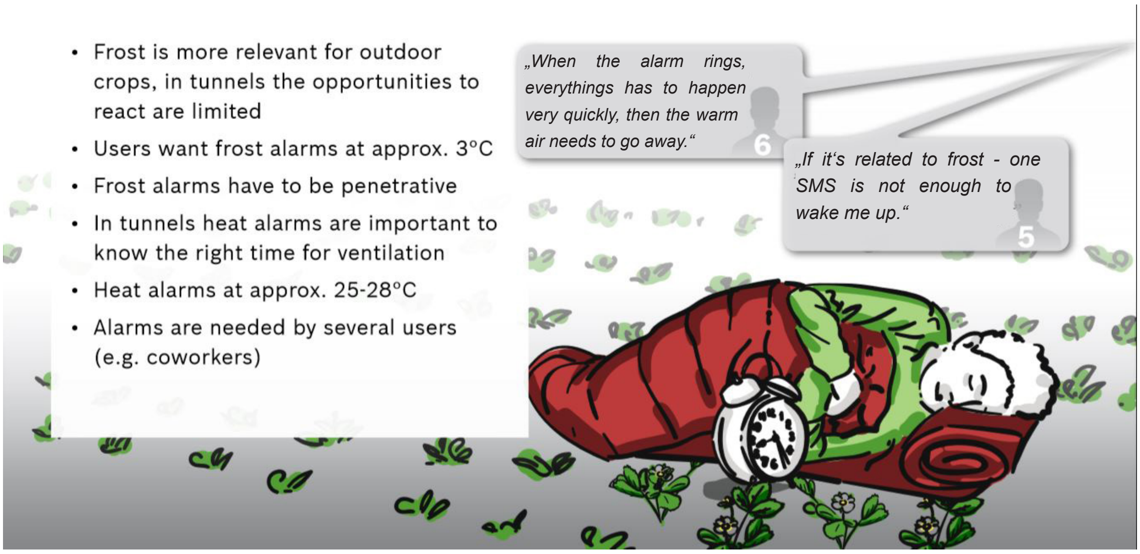


Figure 21 - Regarding sensor alarms (Bosch, 2015)

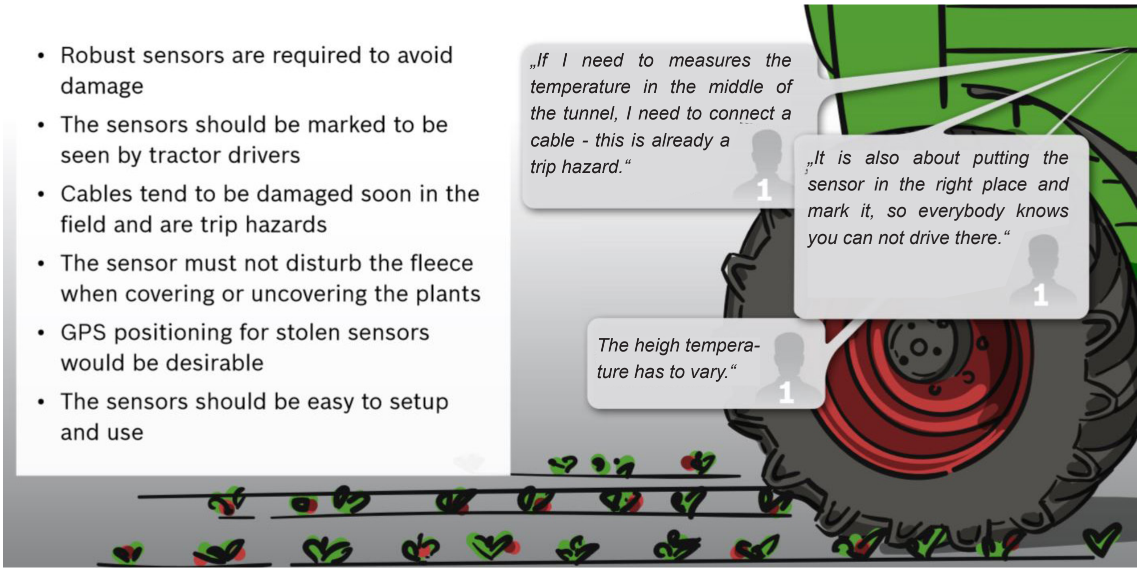


Figure 22 - Hardware requirements (Bosch, 2015)

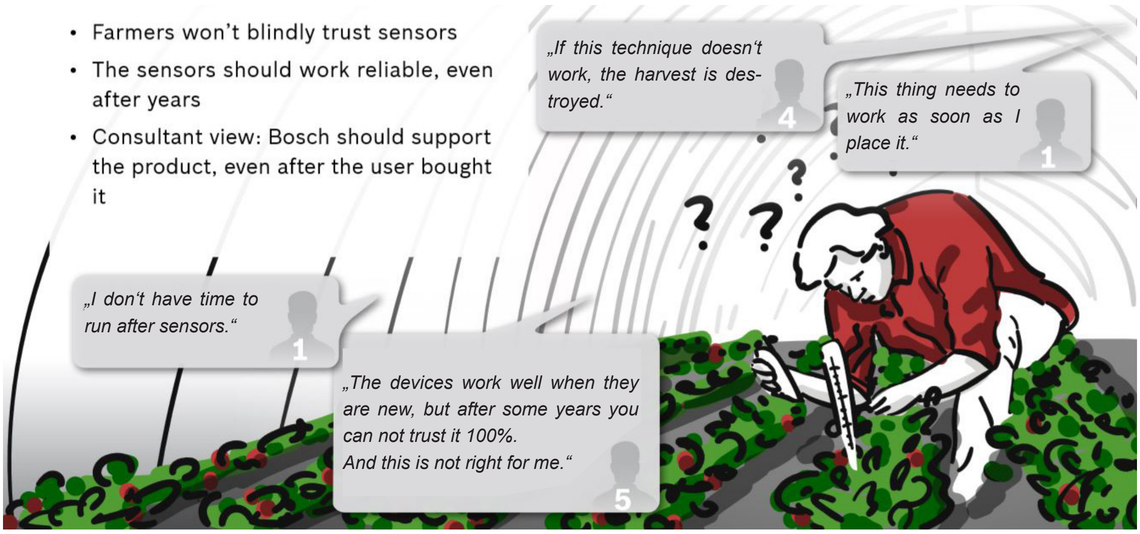
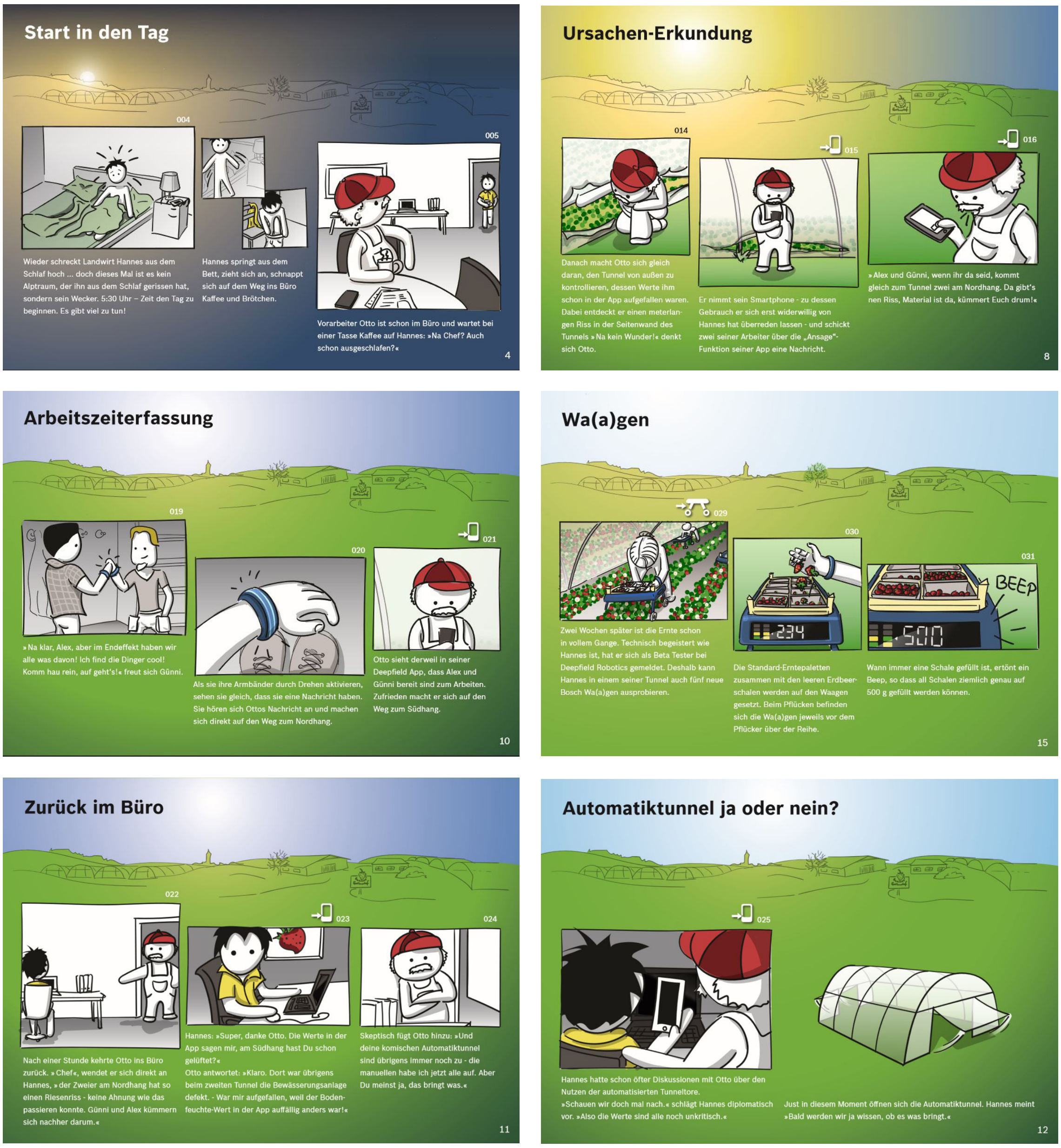


Figure 23 - General reliability (Bosch, 2015)

Drawing on the previous research and with the results from the actual one, Bosch developed four concepts that were tested with the users in order to get feedback about potential ideas and thus, develop a further concept. Bosch created this time a storyboard compelling all the concepts into one history, so the farmers would be easily immersed into it, and three prototypes to support the presentation (the image bellow aims the layout representation of the storyboard, since the text was written in German and was deliberately not translated):



Figures 24 - Storyboard visualization (Bosch, 2015)

3.2 Concept Automatic-gate

Depending on the measured values the automatic tunnel gates open and close automatically. Without workload an ideal ventilation of the tunnel is realized. Additionally, the tunnel gates can be opened and closed remotely with the app.

Figure 25 - Concept Automatic-Gate visualization (Bosch, 2015)

Figure 26 - Concept Automatic-Gate testing (Bosch, 2015)

Concept Automatic Gate • Results based on user testing
Concept with good potential, fits very well to general sensor concept • Main benefit seen in labor and cost reduction • Realization has to be easy, flexible and cost efficient

Table 8 - Concept Automatic-Gate Test Results

3.3 Concept Yield Trolley

Connected trolleys assist with the harvest recording. Co-workers put the harvested fruits into a trolley. A scale measures the weight of the fruits and compares it with the covered distance. Predictions can be made about the expected harvest volume. All data can be used for documentation.

Figure 27 - Concept Yield Trolley visualization (Bosch, 2015)

Figures 28 - Concept Yield Trolley visualization (Bosch, 2015)

Concept Yield Trolley • Results based on user testing
Concept strongly polarizes farmers (for consultants a 'must have') • Harvest forecast in real-time and over distance relevant • Realization needs re-work, current solution perceived as premature and isn't seen as a ready for production solution

Table 9 - Concept Yield Trolley Test Results

3.4 Concept Sensor Package

The sensor devices are distributed in the fields or tunnels and measure four temperature and two humidity values: soil temperature, under fleece and over fleece, outside temperature, air and soil humidity. These values are shown on a smartphone app.

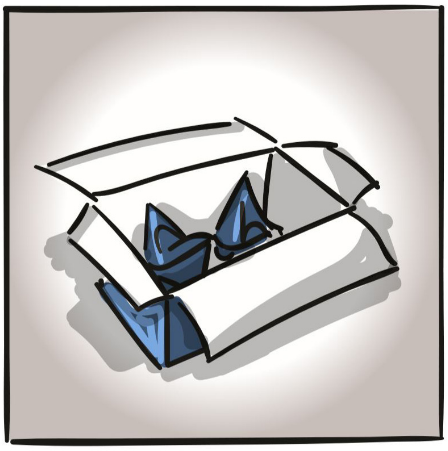


Figure 29 - Concept Sensor Package visualization (Bosch, 2015)

Figures 30 - Concept Sensor Package testing (Bosch, 2015)

Concept Sensor Package • Results based on user testing
Concept with highest potential • Farmers perceive it as universal and relevant • Not all measurement values for every farmer relevant at first sight, but potential for future 'learning'

Table 10 - Concept Sensor Package Test Results

3.5 Concept Wristband

Every Co-worker has a wristband to record his working time and breaks. The working hours can be viewed via application and printed for documentary purposes. During harvest the working time can be recorded more efficiently to fulfil legal regulations. With an application farmers can make announcements to all co-workers with wristbands.

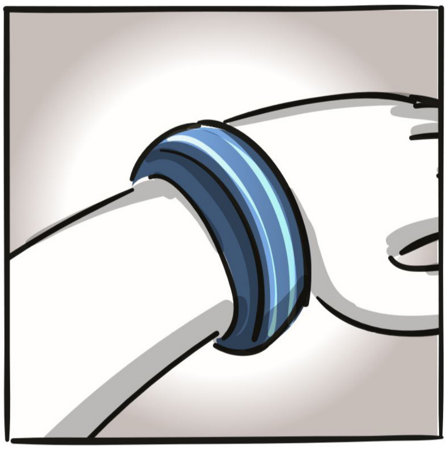


Figure 31 - Concept Wristband visualization (Bosch, 2015)

Concept Wristband • Results based on user testing
Farmers see voice mail function in general not as beneficial • Ambivalent time registration function • Combination of harvest and time registration essential to fully address farmers' needs • Time tracking for legal purposes is a common pain point

Table 11 - Concept Wristband Test Results

After a session where they analysed every feedback, it became clear the preference of having a universal sensor device among other concepts:

Figure 32 - Workshop Feedback Session at Bosch (Bosch, 2015)

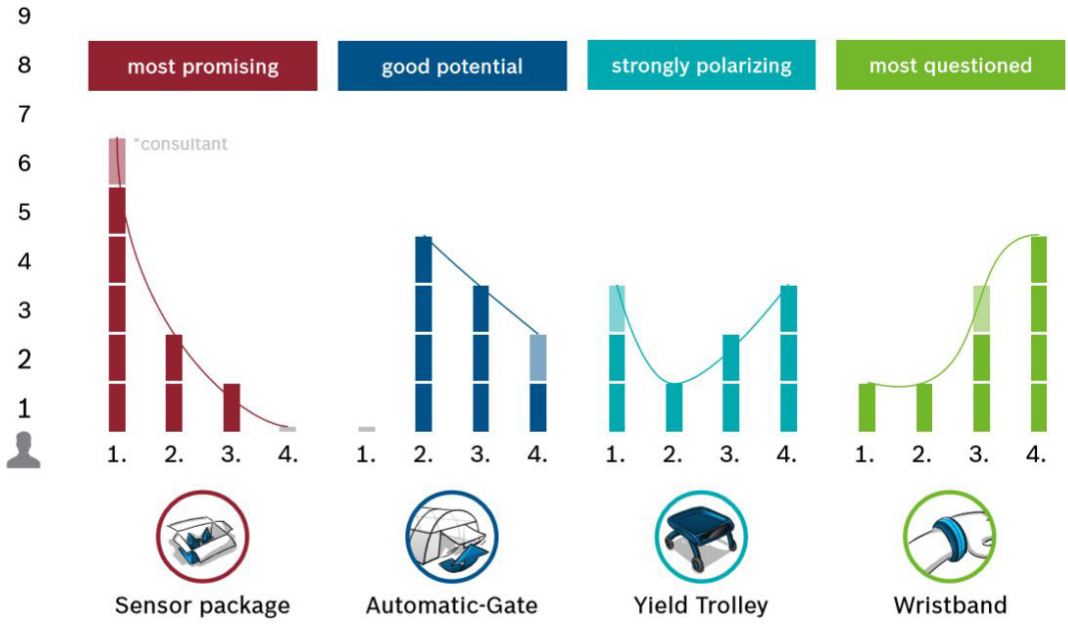


Figure 33 - Concept Ranking (Bosch, 2015)

It is important to bear in mind that the studies have a qualitative approach and for this reason, no quantitative analysis with percentage is available. This is due to the fact that the quality of information can provide deep and detailed insights that will later on help on the product development. Those insights are often mentioned or observed during in-site interviews and therefore do not provide any relevant amount for a qualitative study. Bosch bear its decisions on the rich and contextualized understanding achieved by the human-centered approach.

As a brand with a great reputation, Bosch is able to test their prototypes already on the market and from the collected feedback, to upgrade their next product generations, i.e. their current device *Deepfield Connect.* Bosch holds a close relationship with their users and are ready to listen critics in order to improve their products. So far, Bosch had great feedback regarding yield improvement (regardless of number) and, therefore, is still working on future improvements for the next generation.

Both studies provided a solid foundation for this Final Project Work: design a universal device for agriculture, and moreover, granted this Final Project Work with rich information about farmers' needs and their working environment. Most of the design literature agrees that rich information about users' needs and wishes collected in the fuzzy front end is a determinant of success (see Cooper and Kleinschmidt, 1987; Cooper, 1994; Zirger and Maidique, 1990; Norman, 2005; Welch and Odegard, 2015).

It is challenging for designers to create empathy for the users, when not participating directly in field observations and interviews (see Suri, 2000), however, as the next Chapter shows, a study of both studies, supported by HCD methods, were made carefully in order to surpass this issue.

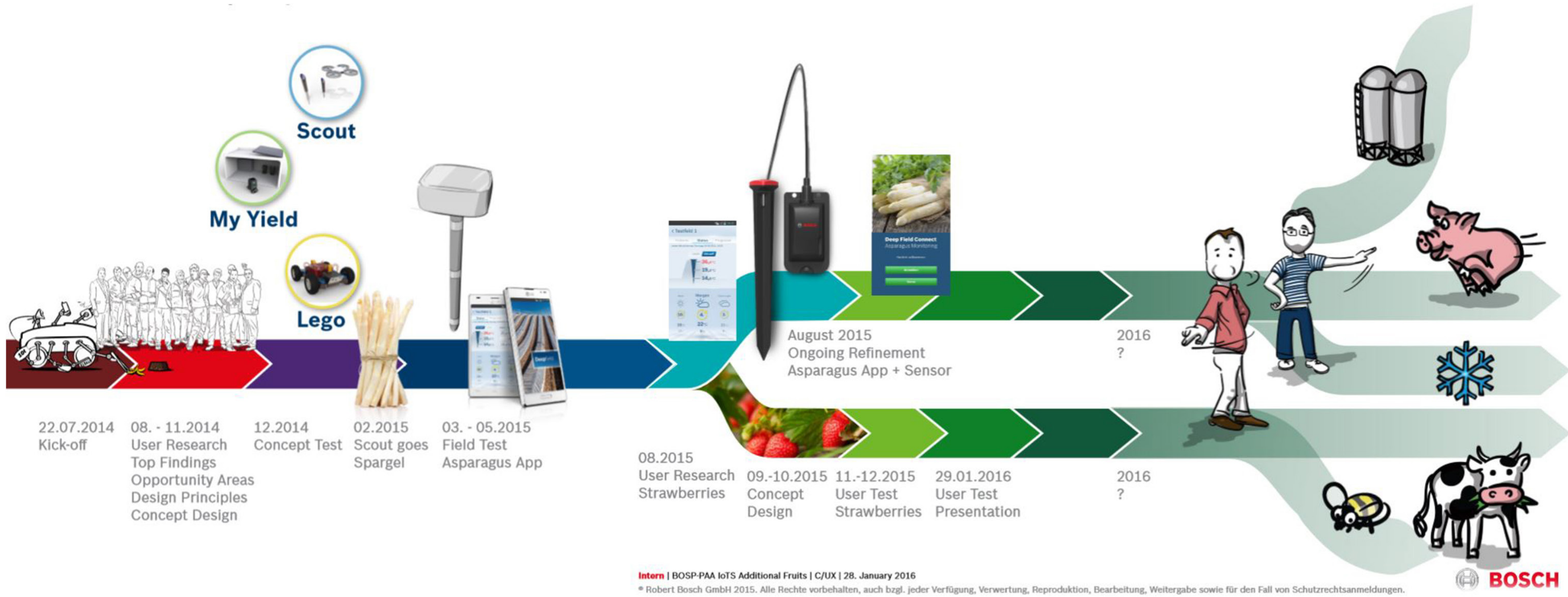


Figure 34 - Project process development (Bosch, 2015)

4 Statement

Based on both researches and theory, it is possible to state that a creation of a sensor device for agriculture is viable and relevant for farmers and stakeholders, since it best fulfils agricultural needs enhancing the quality of activities in the landscape care.

CHAPTER FIVE

THE DESIGN PROCESS

1 RESEARCH DESIGN PROCESS

2 FINAL DESIGN

3 HOW IT WORKS

4 TECHNICAL SPECIFICATIONS

5 MARKETING

1 Research design process

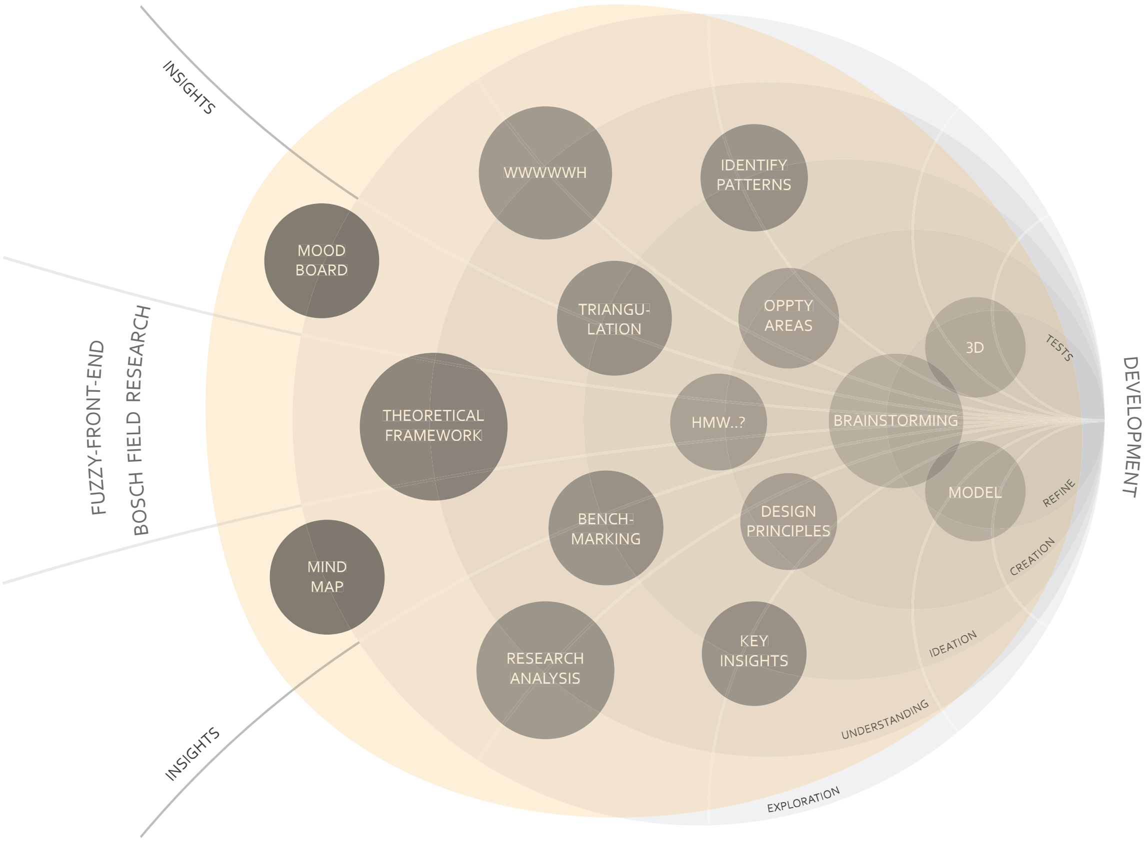


Figure 35 - Design process

The graphic above illustrates the stages of the design process, and shows where this Final Project Work actively took place in the whole design process (yellow part). It is a continuation of the *fuzzy front-end*, where both Bosch projects were positioned. Initially, the outcome from both studies was unknown (whether resulting in a product or a service), resulting mostly in a chaotic front end, but the goal of these explorations in the *fuzzy front end* is to identify what has potential to be further developed (see Sanders and Stappers, 2008).

The design process was based on a logic sequence, beginning with exploration, followed by understanding, ideation, creation, refinement and finally development. However, as usual, the whole process did not follow a linear system, as methods and activities were occasionally being overlapped (see Ulrich and Eppinger, 2015). In addition, the focus lays after the research phase, since Bosch already carried interviews and observations in order to identify the users' needs. These studies were made without the designer's participation, however, even though the ideal is to bridge the gap between research and design at the very beginning of the design process (see Sanders and Stappers, 2014), a clear analysis of the data was possible, due to the consistency of the documented information prepared by Bosch. With the use of Personas and User Journeys as means of given structure to the data, the designer can be easily immersed in the users' perspective and, thus, benefit from the experience (see Sanders and Stappers, 2014). Such tools have the power to transform raw information into a dynamic material, helping designers to gain more empathy and interest for the users. Today it exists a wide variety of tools and methods that help designers to create meaningful experiences rather than purely things (see Suri, 2003).

The exploration phase in this Final Project Work had the purpose to create an empathy with the context, rather than gathering information. At this stage, it was created a mind map (Figure 37) to become acquainted with the subject and the whole environment. The mind map was created to bring structure and clarity to the theme, as it maps all the relevant aspects around the problem and provides an overview of the topics. This helps to connect issues and sub issues, as well as find the keywords to state the problem and start the literature review (see Boeijen *et al.,* 2014). Afterwards, the creation of a mood board had the aim to inspire and communicate emotions through images, as well as stimulate the creativity during the process (see (McDonagh, Goggin and Squier, 2005):

Figures 36 - Mood board

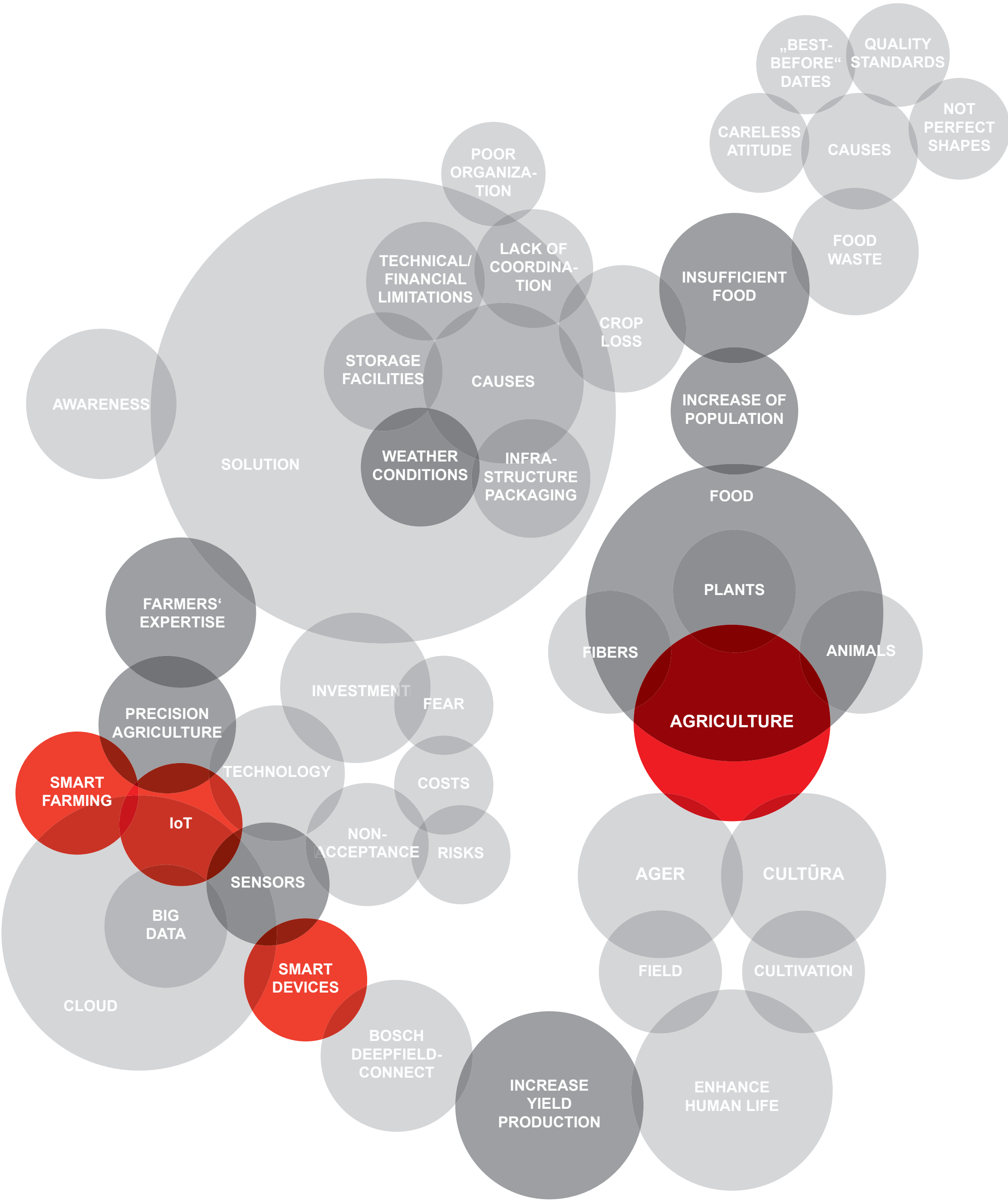


Figure 37 - Mind map

The next phase had the aim to understand better the farmer and its environment. It is of great importance to gather a deep understanding of user's “aspirations, attitudes, behaviours, emotions, perceptions, processes, and motivations within their prevailing and evolving social, cultural, and technology context” (Suri, 2008, p.56), as they serve as inspiration for designers to create innovative solutions. At this point, the tool WWWWH (Who? What? Where? When? Why? How?) was used to reflect on the context and structure the information (Figure 38). Hereupon the study of data gathered by Bosch started. Since both studies led to concrete concepts, the scope of analysis was very broad and not only limited to the field research, but also covered the whole process, including feedback from the concepts generated within both projects, which were vital for this Final Project Work. The analysis of the raw data did not take place in this Final Project Work, as questionnaires, interviews, photographs, informal conversations and video-recordings were all compiled, interpreted and structured earlier by Bosch with the help of tools, as, e.g., Personas and User Journey.

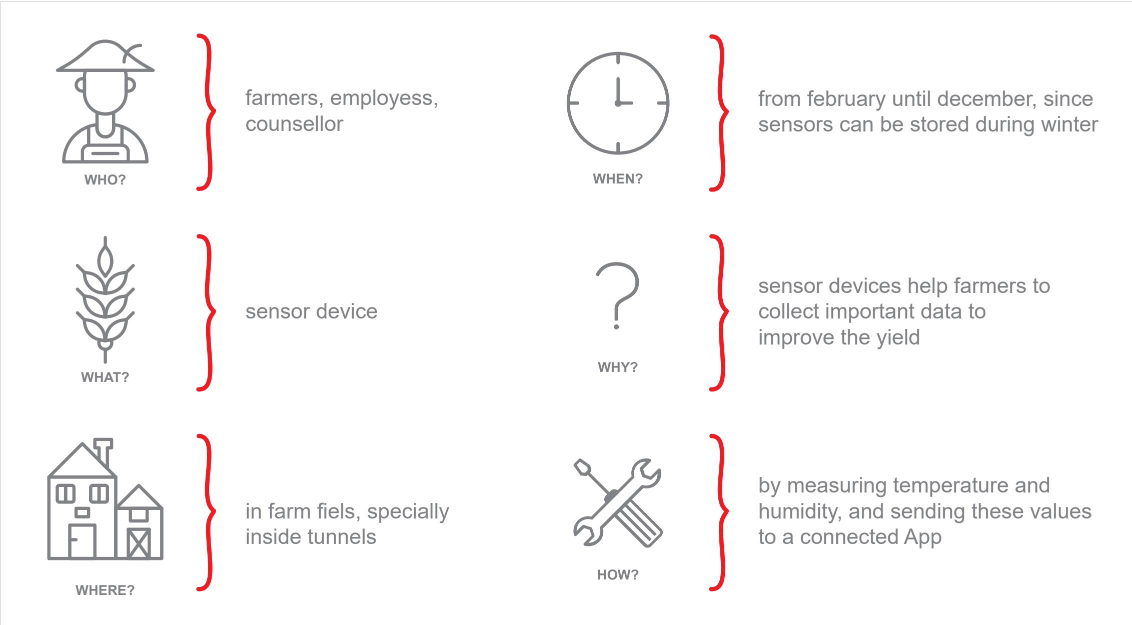


Figure 38 - WWWWH Tool

Nonetheless, considering that one unique data can lead to a variety of interpretation (see Sanders and Stappers, 2014), a study of neat data was also made, i.e., a collection of quotes stated during the interviews was previously reported and later sorted by the Bosch team, however, in this case it was important to review all the quotes likewise, as relevant information purely about sensors could have been possibly ignored on the selected ones.

Thereupon, with the help of the triangulation method, it was possible to compare the insights from both, research and theory: i.e. Gartner (2014), Accenture (2015a) and Norman (2013) emphasize the importance of having a simple appearance and usability in devices that own high technology; likewise, farmers wish an effortlessly and unambiguous device. Moreover, even though this Final Project Work did not deal directly with the raw data collected straight from the fields, the whole amount of information is yet messy and need to be organized in order to make sense. This coherence can be achieved by identifying emergent patterns and relationships between the information, and for this, quotes, observations and theory are interpreted and transformed into key insights. It is an abstract and challenging process, but the insights are the wisdom of the whole information collected and finding them helps to structure thoughts and give reason to the data (see IDEO, 2011). The following activity was held to uncover the insights: quotes, observations and arguments were narrowed and organized per similarity in order to state an insight.

Figure 39 - Identifying insights

Adaptability is a decisive factor • No time should be spent searching the device in the fields • Experience will be always important • Farmers appreciate field activities • Usability is a key factor • Devices must have a long operating life • Farmers do not want to spend time understanding high-technologies • Devices have to be handy

Table 12 - Key Insights

After the key insights were identified, the process proceeded with organizing them by themes to bring more structure to the information.

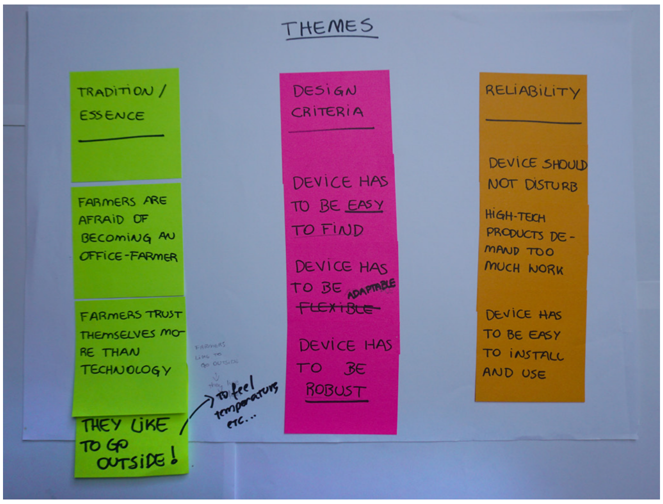


Figure 40 - Identifying themes

TRADITION/ESSENCE	TANGIBLE CRITERIAS	RELIABILITY
Fear of becoming an office-farmer Experience will be always important Farmers appreciate field activities	Device has to be: easy to find adaptable robust handy	Device should not disturb High-tech devices should be understandable They trust their expertise

Table 13 - Insights organized by themes

Along with structuring the key insights, scope for promising ideas possibly addressed by innovation were identified. The method “How might we…?” (see IDEO, 2011)helps to translate the insights into future opportunities, which are not a solution per se, but rather an opening for new ideas.

Figure 41 - HMW...? Tool

How might we...?
… provide farmers with a product that doesn't tell them what to do, but rather help them on decision-making? or ... create a device that helps farmers' management without taking away their sense of control? **By applying PA principles with a device that simply measures data that farmers can not and by avoiding the creation of a device that is fully automated.** ... encourage farmers to use a sensor device? **By providing flexibility, trust, convenience, comfort.** ... provide a positive experience through the use of a sensor device? **By addressing their needs, such as the wish of having a simple and reliable device.** ... enable farmers to see the product in the fields? **Either with a GPS tracking system, lights or by creating a device that does not hide under the plants.** ... create a product that adapts to the farmers' crop so it can work properly? or ... create a product that adapts to farmers conditions so they can adjust it to their needs? **By creating a device that it is universal and adjustable.**

Table 14 - HMW...? Tool

It became increasingly clear that, not only each crop requires different care, but also the plant itself has specific efforts. In order to avoid frosting e.g., farmers need to use a fleece to protect the plants and the sensor device should not damage, destroy or hinder the fleece (Figure 42). In contrast, devices that have a specific height can create a shadow that might affect the temperature values (Figure 43).

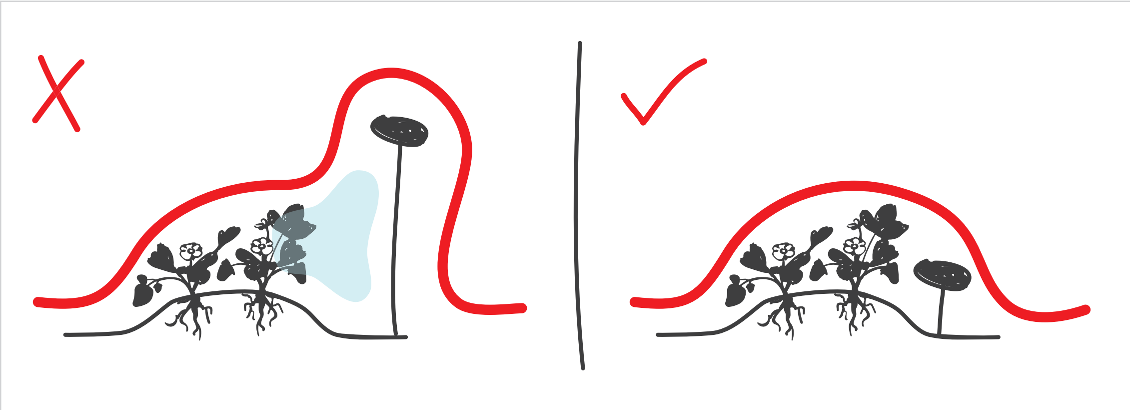


Figure 42 - An example of how devices disturb the fleece

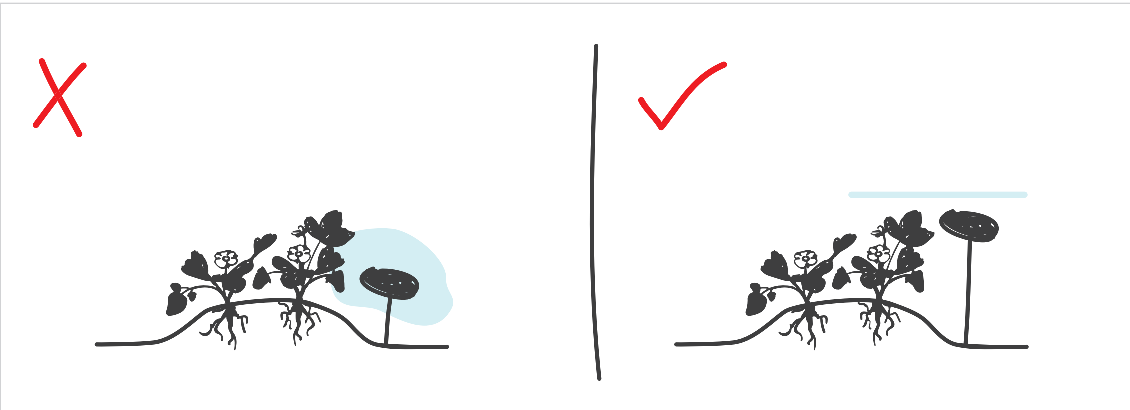


Figure 43 - An example of shadow created by plants that are higher than the device

With this in mind, the first vision was *to create a device that "grows together" with the plant*, so the device would have always the same size as the plant, and thus, not disturb the fleece. Since ideas were starting to emerge, the shift to the ideation phase gradually began. Nevertheless, ideas that arise early in the process are more likely to be superficial and somewhat abstract, but should not be discarded. Although the DIKW analysis (D stands for data, I for information, K for knowledge and W for wisdom) shows that ideas emerging at the wisdom level tend to be more significant and bigger, all ideas arisen during the process are valid and can serve as inspiration at later stages (see Sanders and Stappers, 2014).

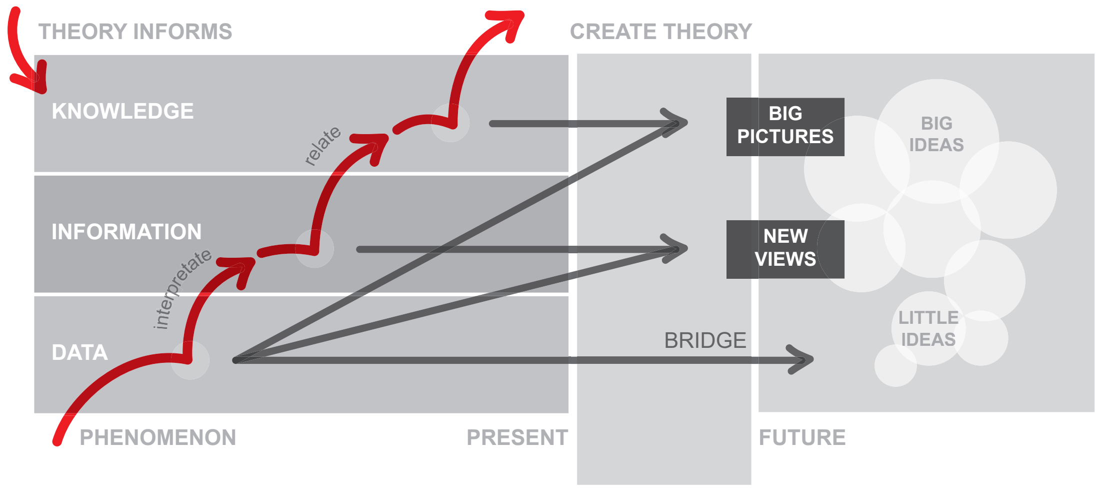


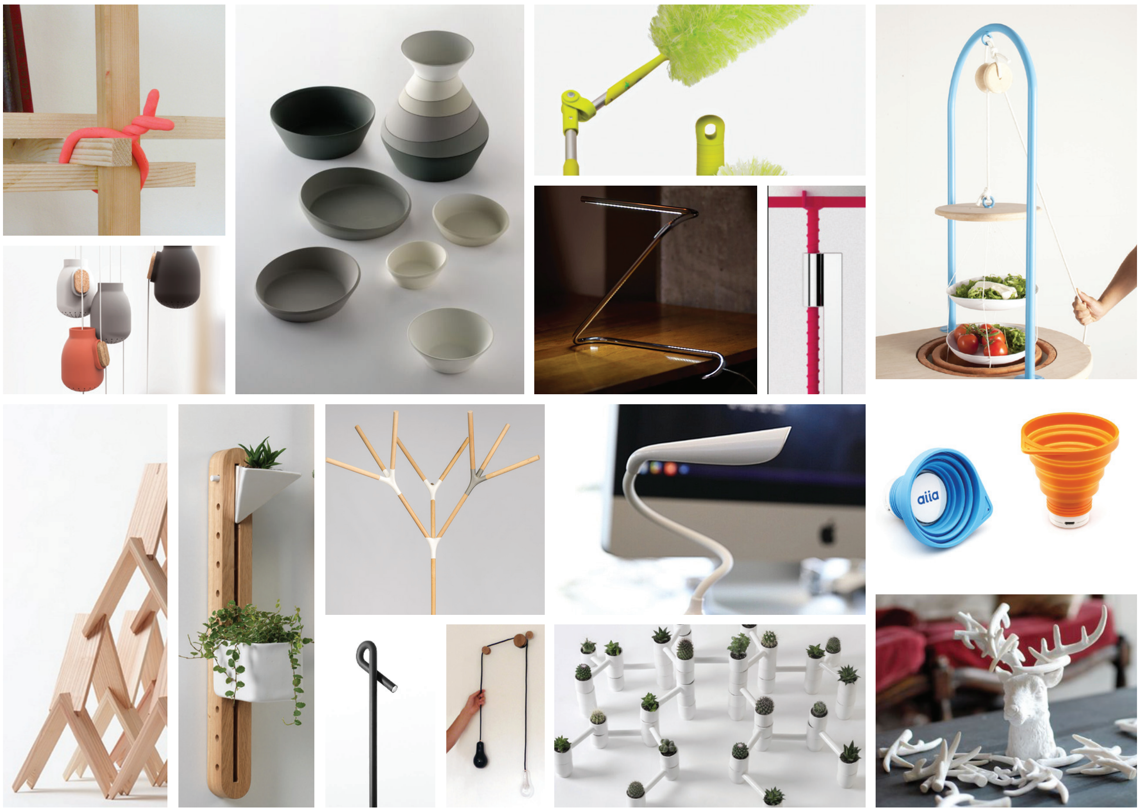
Figure 44 - DIKW Graphic (Adapted from Convivial Toolbox, 2014)

Over the process, design aspects were starting to be clear. Defining design principles is a way of guiding the concept evolution and “give integrity and form” to the design (see IDEO, 2011).

Design Principles
RELIABILITY • ROBUSTNESS • VISIBILITY • FLEXIBILITY • VERSATILITY • CLARITY

Table 15 - Design Principles

Hereupon, a search for new materials, forms and mechanisms started to take place and a collection of images was composed (Figure 45). This collection is a powerful way of communicating visually solutions that other products possess and can serve as inspiration for future developments (see Suri and Marsh, 1997).



Figures 45 - Images collection of possible solutions for inspiration

At the ideation phase, a visualization of ideas through quick sketching, a dynamic way of expressing ideas into concrete concepts, was being made. Here many ideas were generated and later compared with insights and design principles. For instance, many possible solutions to solve the *height and depth problem*, e.g. by employing a screwing mechanism or an extension pole as some telescopes have (Figure 47), were generated.

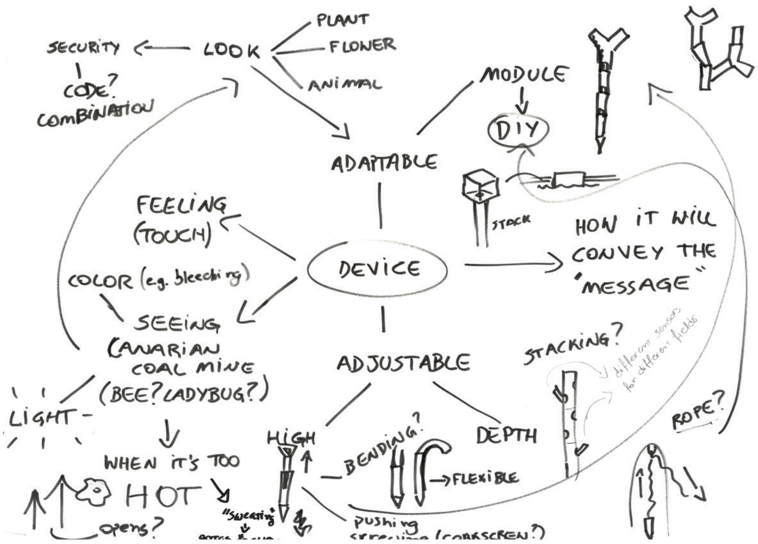


Figure 46 - Brainstorming

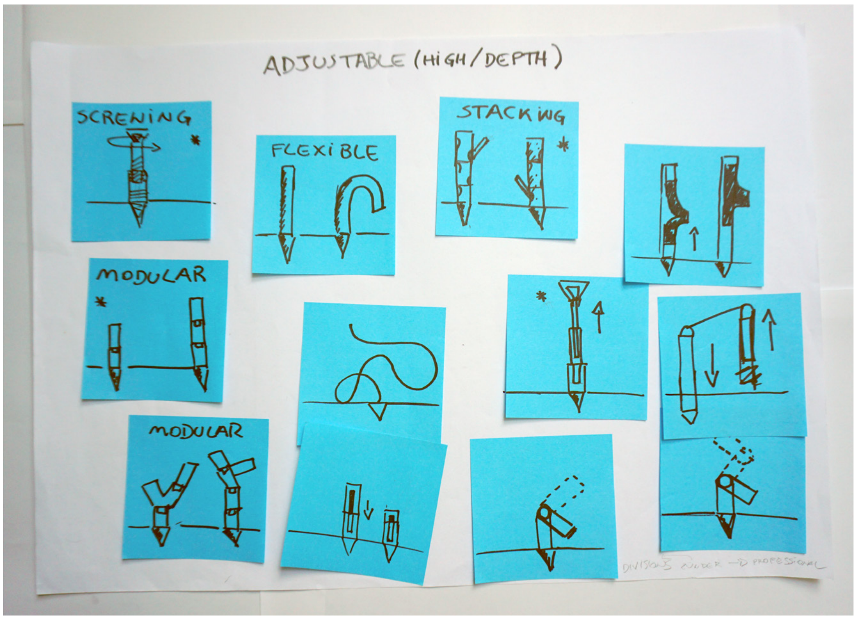


Figure 47 - Quick sketching

After meeting the team to present the first possible solutions, the modular system had a preference among the others, based on the insight that farmers like to build and repair things by their own. Additionally, a modular concept, such as Lego, give the people freedom for imagination and the feeling of control, and, even more, the modular concept matched greatly the idea of "growing together" with the plant.

Nonetheless, prior to sketching concrete ideas and defining the product gestalt and aesthetic details, the Bosch Design Guideline (Bosch, 2016) was studied in order to incorporate the design language of the company into the product. Designers have the ability to express the brand essence through a product, by not only considering tangible aspects, but also the whole mind-set of a company, as product design should be "a direct translation of the culture for which a company or brand stands" (Stompff, 2003, p.32). Borja de Mozota (2003) considers a product the "gestalt of a brand", which involves physical and subjective aspects, and the product design language, which refers to the style of one or more products; moreover, product design has the power to express beyond the aesthetical elements; it should be seen as a major driver that communicates other assets of a brand, as quality and mission.

Bosch Design Guideline gives directions to translate their values into unique products, thus, making them recognizable through their characteristics. Products that have the power to reflect their strong brand personality through a consistency of elements become distinct from competition (see Mumgaard, 2012). A unique design creates instant product perception, that will later transform the consumer behaviour towards that product based on their experience, which in turn will be defined by the product-use satisfaction (see Kotler and Rath, 1984; Borja de Mozota, 2003). A positive product-user interaction helps to develop affective relationships between brand and consumer (see Kumar *et al.,* 2014; Kimmel 2015), that if endured, it can result in a loyal relationship. Bosch affirms to have elegant and functional products that sparks enthusiasm with surprisingly simple solutions.

Figure 48 - Photos from Bosch Desgin Guideline Book

An internship at Bosch Healthcare Solutions and subsequently the daily conviviality during the Final Project Work made it possible to infuse their philosophy and purpose. Bosch focuses on functionality and simplicity to express their quality and based on their principle “Invented for Life”, Bosch generated three new key design elements that will define the next generation of product design lining:

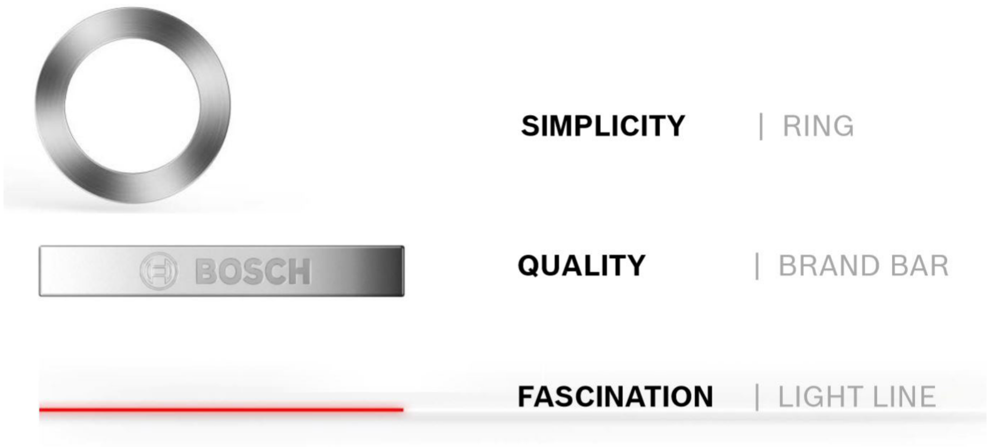


Figure 49 - Bosch Key Elements (Bosch, 2015)

Once it became clear how Bosch translates its brand in their products, the first ideas started to appear in form of sketching, by exploring possible form and function solutions for the device (Figure 50), leading later to the first concrete concept (Figure 51).

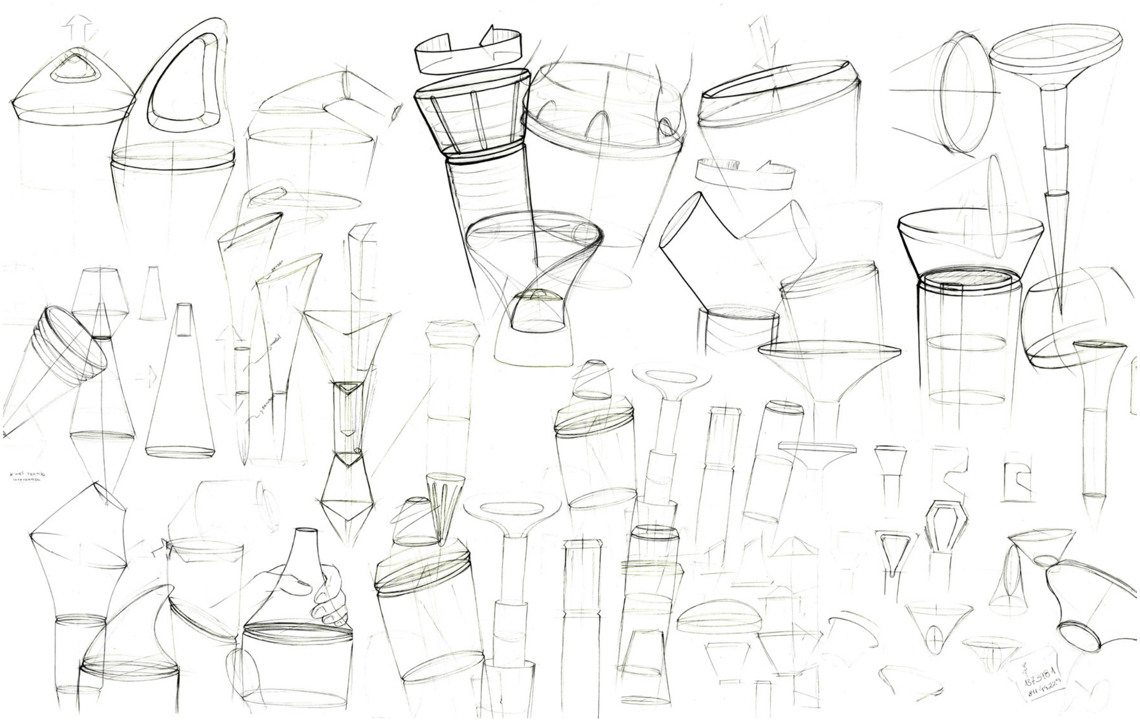


Figure 50 - Ideation sketches

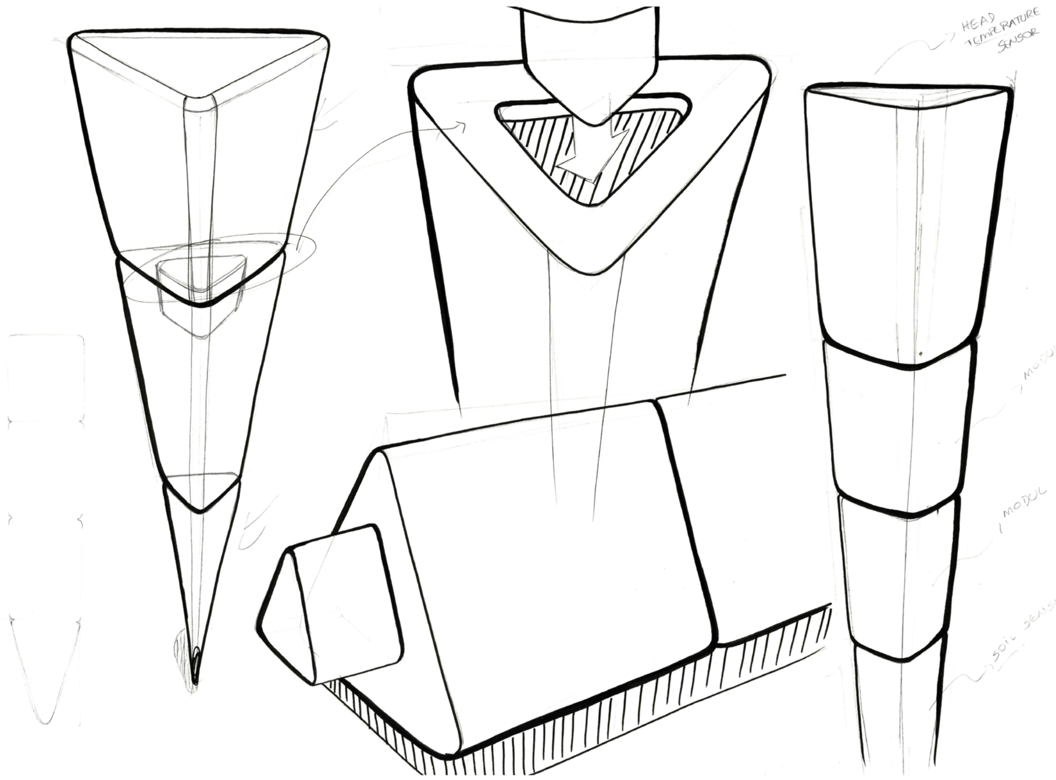


Figure 51 - First concept idea

The first concept employed a modular system, in which the parts could easily attach to one another. The top and bottom part would have the sensors implemented; and extra modules would be available to extend the height when it is necessary. However, when analysing the concept with the team, questions about technical specifications started to appear, since the device would need batteries and electrical components to be able to operate.

The challenge in a good design is the ability to consider not only human factors, but also other disciplines that are involved in the development, such as engineering and marketing, as the product needs “to be reliable, be able to be manufactured and serviced” before purchased by the consumer (Norman, 2013). Therefore, in order to avoid issues that might appear when the disciplines work separately from one another, and prior to any further ideas, a meeting at Deepfield Robotics, an young start-up of Robert Bosch GmbH with engineers, software developers, robotics specialists and agricultural engineers, which is responsible for the development of Bosch Deepfield Connect, took place. In this way, it was possible to understand how the business model of Bosch works: the farmer buys a service where it contains a sensor device, a gateway box and an app.

The earliest gateway box (Figure 52) contained electrical components, such as antenna and a circuit board, and three batteries, which provided a lifetime of approximately two years. Once the battery life is over, the farmer gets a new box, as long as the service is being purchased. The box is connected to the sensor device through a cable; however, one important insight gained during the research by Bosch, was that farmers are unwilling to have cables on the fields, due to possible accidents and easy damages.

Figure 52 - First Gateway box

However, Bosch decided recently to develop two separated boxes: one for temperature sensor, antenna and board, and another one for batteries (Figure 53). This is due to the need to have the case with three components able of operating independently from the sensor device, which is placed on the soil, and from the batteries' case. As a result, the device offers more flexibility to the user.

Figure 53 - Next generation of the Gateway box

Hence, the farmer purchases the service according to his needs and Bosch does not need to produce different products. This is a strategic decision that the designer needs to cope with, as the business case from a company involves key factors, such as profitability and feasibility (see Chhatpar, 2007). Thereupon, the next ideation section had the aim to develop concepts that would incorporate the electrical components in the device, so that they could work separately as well, but eliminating the need for cables. Although in this case, the designer was not able to change Bosch's business model, the engineers emphasized that they were open to new designs, provided that the components remain the same. Both disciplines were trying to collaborate, even though each considers different leading aspects on the development process (see Norman, 2013; Lloyd and Scott, 1994).

As farmers prefer rather a discreet device, compact sizes and a clean appearance were more inclined to be explored. However, another challenge was the batteries and circuit board's size. Three D-cell batteries (34.2 x 61.5mm), a circuit board (50 x 92 x 20 mm), one aerial for GPS (25 x 25 x 8 mm) and one aerial for GSM (25 x 80 x 8 mm) had to be placed inside the device, if the idea of eliminating the need for cables would remain. Here, a quick research was made to find smaller batteries that could provide the same features. Future concepts, such as energy harvesting, were also considered, but the engineers emphasized the importance of preserving the D-cell batteries, since the device requires high energy, as well as the need of lasting two years. Superior battery technologies, as Lithium batteries, were no option due to transport restrictions, even though they would allow smaller device dimensions. Thus, it was not possible to replace the batteries, making it even more challenging to incorporate it discretely into the device.

The next step was to identify the best placement for components. The validation for finding the best position (Figure 54) took into consideration technical requirements, since batteries need to be placed in a certain order to provide the necessary power, easier accessibility and replacement of the components. Bear in mind that the circuit board and batteries need to work separately as well, one module would employ batteries and one module would employ electrical components. Another module to be attached to, would contain the temperature soil sensor.

The module containing the electrical components features the other temperature sensor and should therefore remain at the top of the device, in order to avoid that the temperature values are affected once it stays under the shade of the plant. To achieve this, extra modules would be attached to the *main modules*, extending thus the device to the desired height.

Considering all these aspects, the best placement was defined, and it became clear that in order to fit the components inside, the previous triangular shape would need to become extremely bigger, compared to a circular shape (Figure 55).

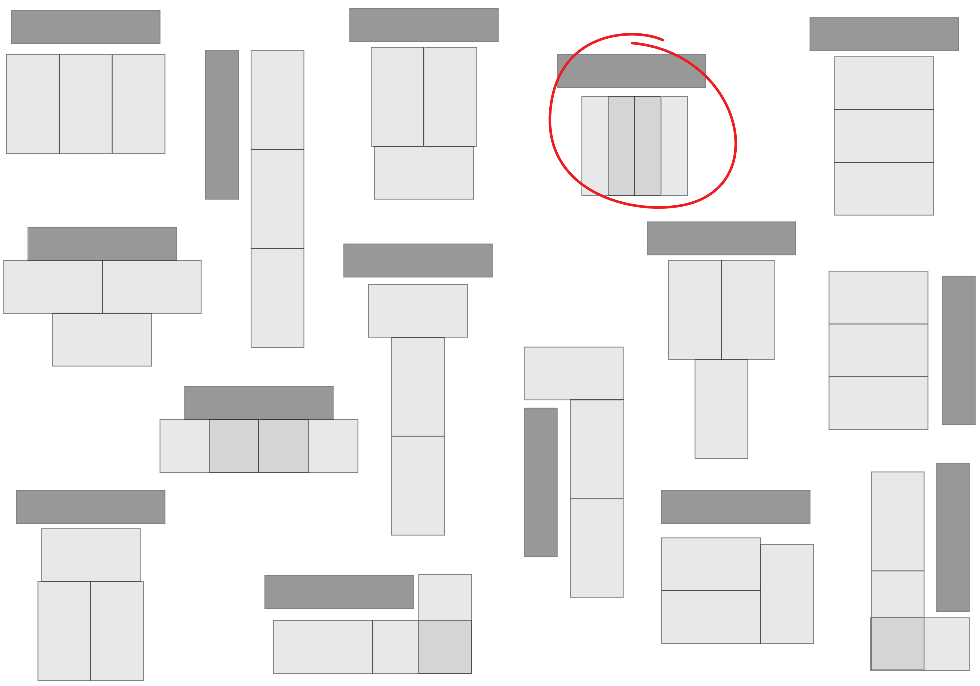


Figure 54 - Components‘ placement exploration

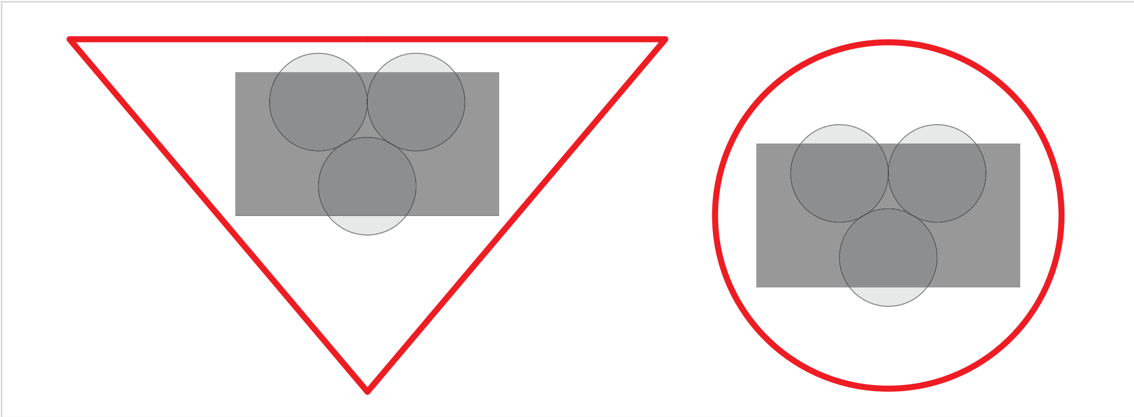


Figure 55 - Top View from components‘ placement and shape validation

It was then established that the shape would rather become circular as it fitted best the components by hardly leaving empty spaces. At this point, the ideation phase focused on the top modules, since they were determining the shape of the device. Thereupon, the shape was explored from the side view, based on Bosch design language, preferring symmetric and simple forms (Figure 56).

For better evaluating promising shapes in a tangible way, foam models were created, as they provide opportunities of, e.g., proportion or interaction evaluation, allowing prompt refinements from the outset of concept generation (Figure 57) .

Figure 56 - Shape exploration

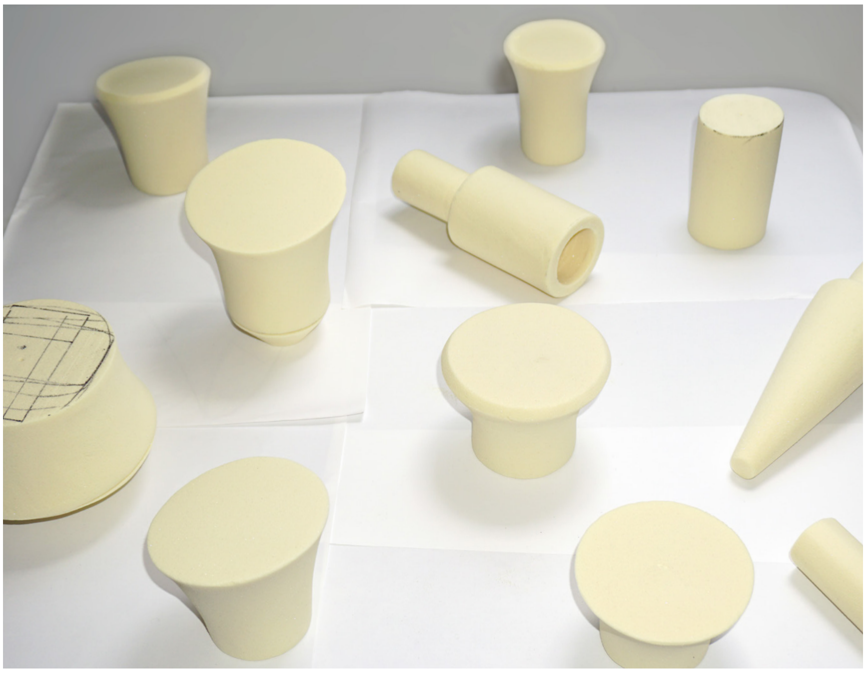


Figure 57 - Model making

The final form evaluation considered how the device would look when the components would be used separately. Since the farmer could decide either if the top part (with circuit board and aerials) would be used attached to the device or not, the components needed to be aesthetically pleasing also when they would operate individually.

Figure 58 - Final sketching

Once the concept gestalt was defined, styling, detail treatments, material selection and manufacturing considerations directed further development. For this, the future product line from Bosch was also analysed and the concept finalised with a 3D model for visualizing the whole components and material choice.

Figures 59 - Bosch Product Line Images Collection

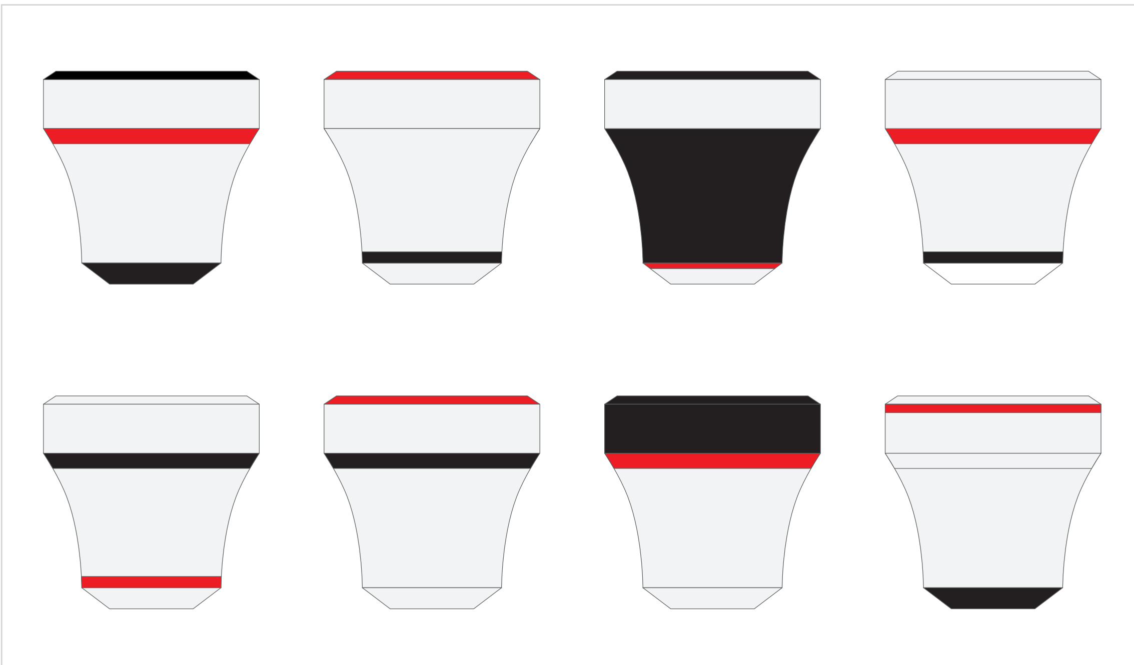


Figure 60 - Colour exploration

2 Final design

Figure 61 - 3D concept visualization

Figure 62 - 3D concept visualization with differet modules

Figure 63 - 3D concept visualization

3 How it works

The farmer receives a kit containing the following items: one case including a circuit board, two aerials and a temperature sensor; one case including three D-cell batteries; two 10x10cm modules; one 15x15cm module; three 5x5cm modules; one 10x10cm stake including a soil temperature sensor; one 20x20cm stake including a soil temperature sensor; one 2m cable; a closing cap and finally a back plate for wall mounting (Figure 65). This modular kit provides the farmer with freedom of using the device in many possibilities according to his wishes. For instance, the farmer can build firstly the *main body* (based on the main usage purpose) by attaching the top case (where the electronic components can be found), the bottom case (where the batteries are placed) and the stake (either the longer or the shorter), as shown in the image below:

Figure 64 - Assembly of the main body

Figure 65 - All items included in the kit

Since the service is the same as previously, the farmer needs to download the connected app from Bosch. Once the app is installed, the available sensor will appear in the screen, so the user can select it and activate it using a serial number. By doing this, it will be possible to study the values that will be in the future send to the smartphone and manage the crop accordingly. But once the *main body* is assembled and the app properly installed, the farmer needs only to stick the device in the mound:

Figure 66 - Device visualization in a real situation

The device will then connect values about temperature and send it every 15 minutes to Bosch Cloud Server, and this data can be accessed at anytime through the connected app.

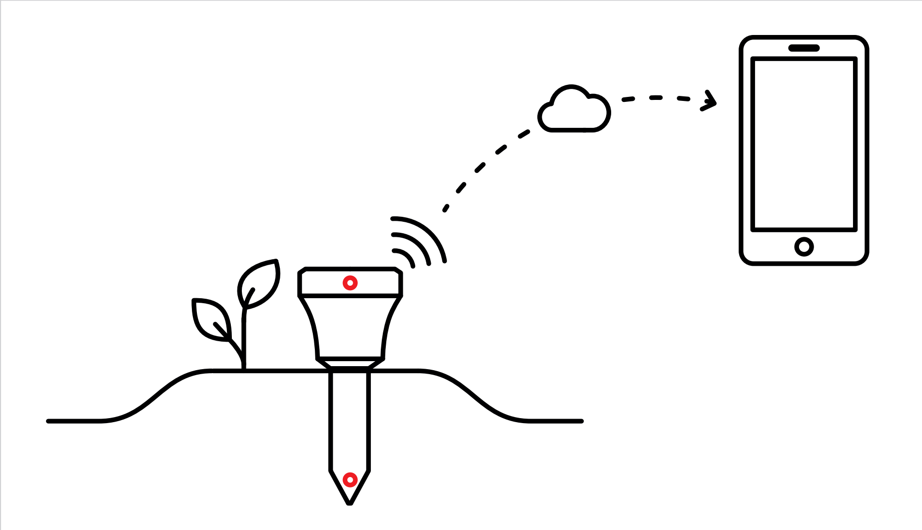


Figure 67 - How the device technology works

The farmer can use the *main body* as long as the plant does not grow above it. When the plants starts to grow, the farmer can attach the modules according to his preferred size:

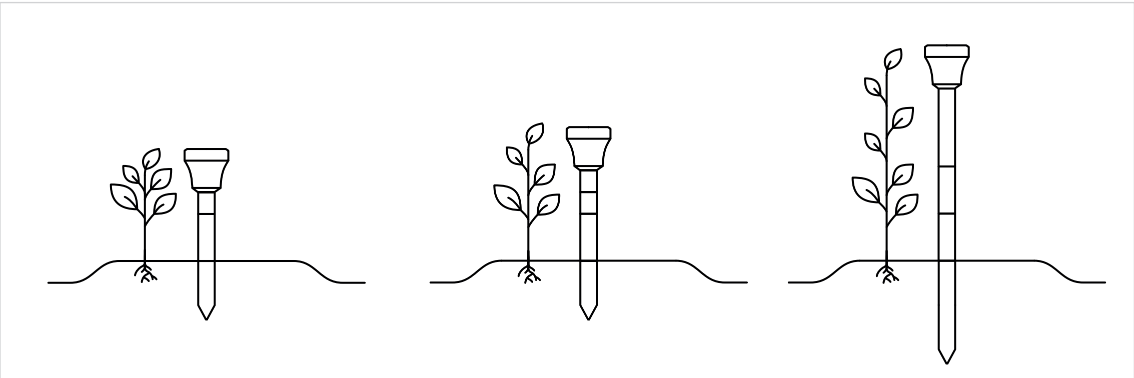


Figure 68 - How the modules can be used

If the farmer wishes to collect the temperature at the level of, e.g., an apple tree, the top and the bottom lid can be hanged on a branch with the help of a cable, since the top lid has an opening for passing a cord (Figure 70). Another example is to use the top lid mounted i.e. on the barn wall. If this is the case, the farmer will need the back plate and the cable, both included in the kit (Figure 71). The following image illustrates the three use cases that were mentioned so far:

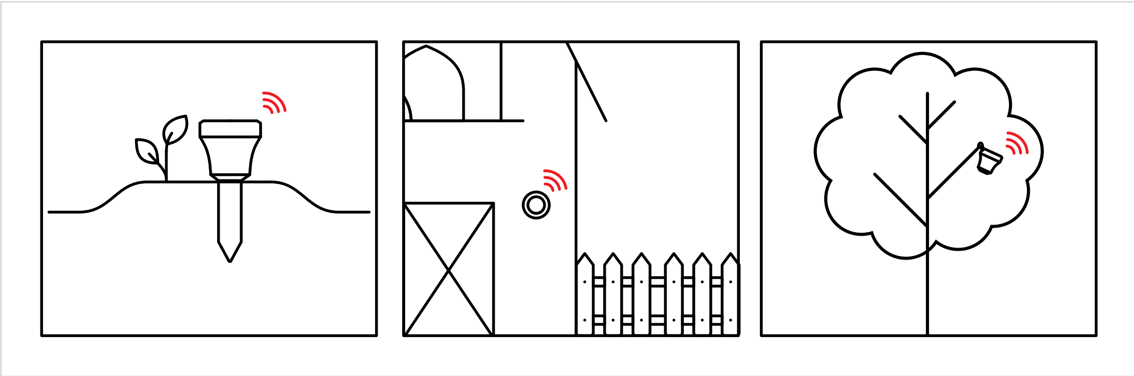


Figure 69 - Use cases

Figure 70 - Detail of the oppening on the top case

Figure 71 - Visualization of the device mounted on the wall

4 Technical specifications

The module concept provide farmers with a device that can easily adapt to different situations by simply assembling the parts. This rapidly assembly was achieved by using a bayonet connector, a quick fastening mechanism. The modules and stake have one side with three radial pins and one receptor side with three slots, where the pins slides until it is not possible to rotate anymore (Figure 72). The top and the bottom case also employ a bayonet mechanism, but similar to the ones that some camera lens have, as it requires less space by using flattened tabs around the base (Figure 73). All parts features electrical contacts to communicate with one another, pins on the upper parts and metal strips on the modules. The correct assembling of the parts is ensured by a marked line displayed on the device.

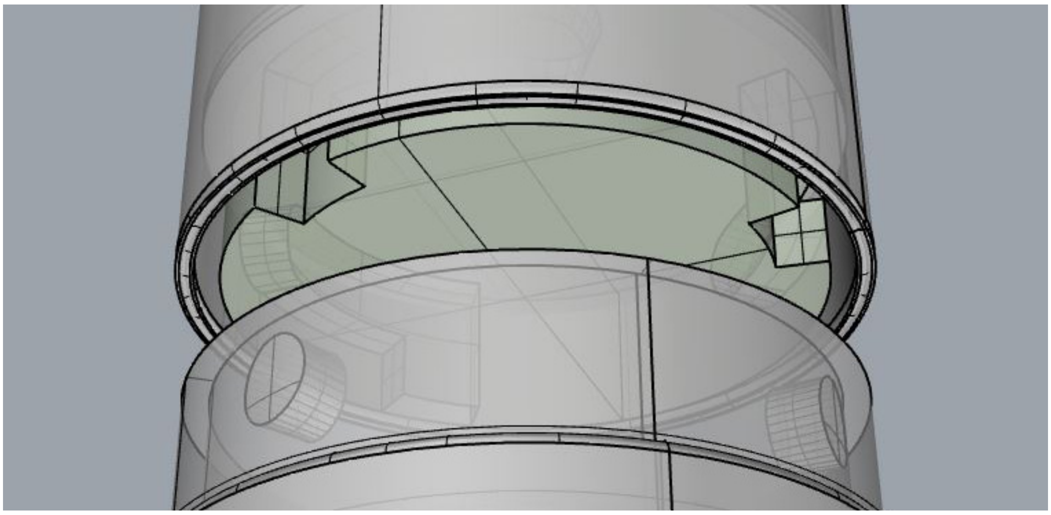


Figure 72 - Bayonet for the modules

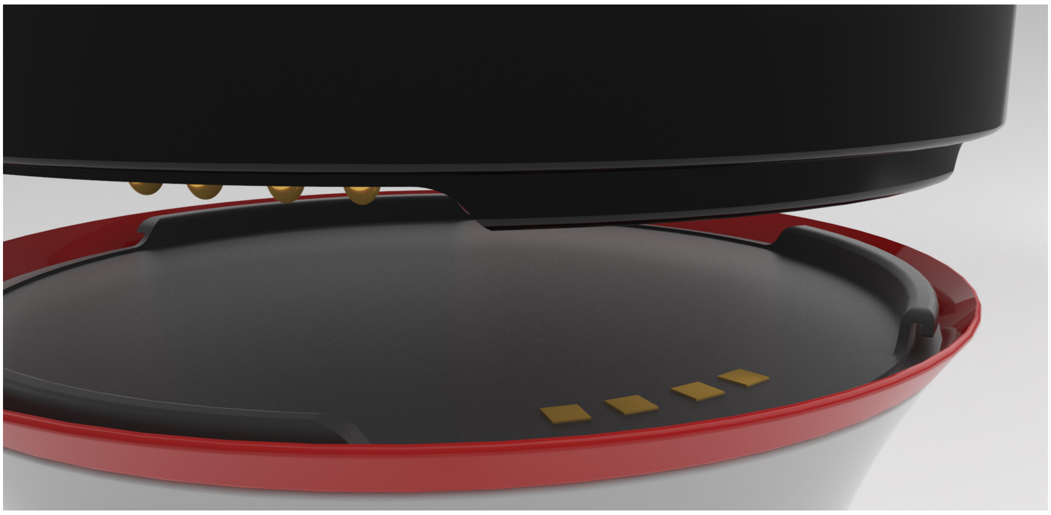


Figure 73 - Bayonet and Electrical contacts

The exploded view illustrates the components located on the top of the device. The user will not have to handle the components, and they will come close and ready to use. When the batteries are empty, the farmer will contact Bosch and receive a new battery case.

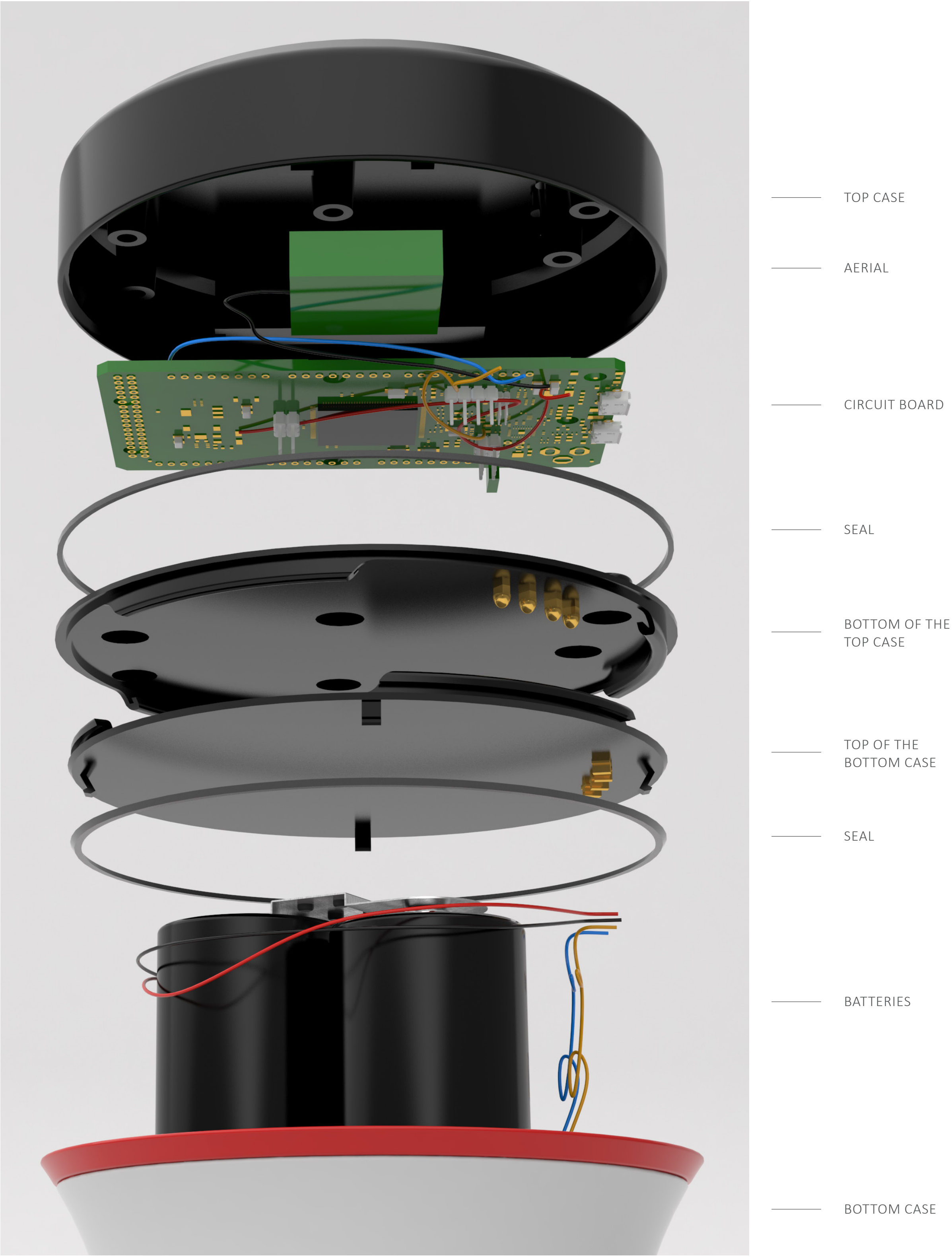


Figure 74 - Visualization of the device mounted on the wall

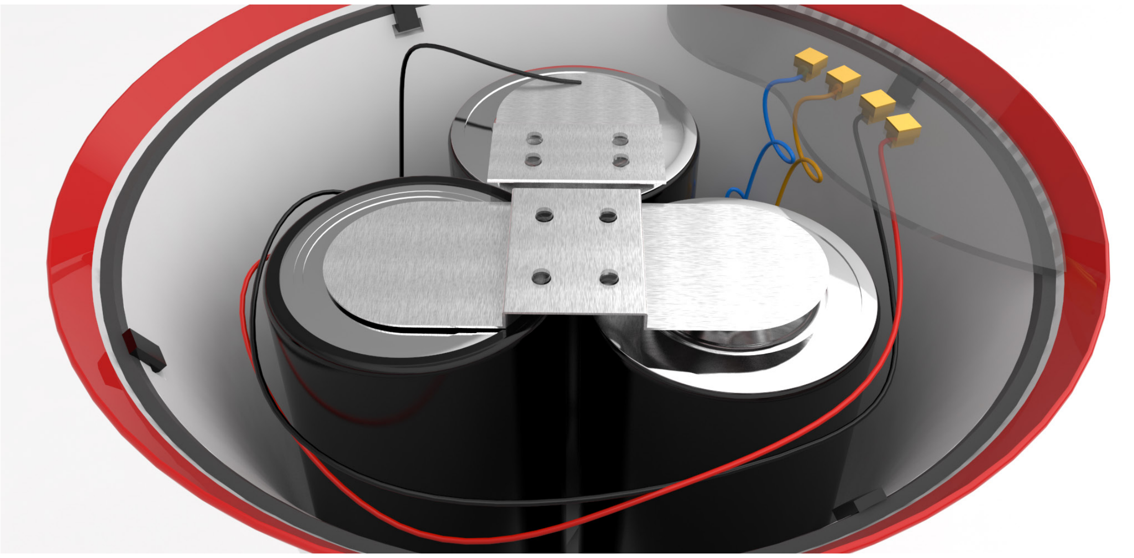


Figure 75 - Visualization of the battery connection

The batteries are connected in series, so the voltage is increased. Lights at the top of the device signalizes whether the battery is empty, by the red blinking light, or if the signal is being successfully sent, by the green light.

Figure 76 - LED lights for visual interaction

The device is developed by the following manufacturing process: overmolding, for parts the contains two materials, as the top part (plastic and electrical contact pins), and the 2K molding, for the bottom case, as it contains two colours.

5 Marketing

In case the product is developed in the future, it is recommended to create a marketing campaign directed to stakeholders (farms industry, farmers, consultants, etc.) in order to promote the product. Bosch already posses contacts and rich data about their consumer, which facilitates the spread of information. The campaign can be made through media including, among others, television, online platforms and print, following the new Bosch Corporate Design, which was presented this year and is being gradually introduced in the market. The new corporate design includes a super-graphic element (Figure 78) and provides also a bigger colour spectrum (Figure 79), turning the Bosch design language more vivid and modern.

Figure 77 - Photo from Bosch Desgin Guideline Book

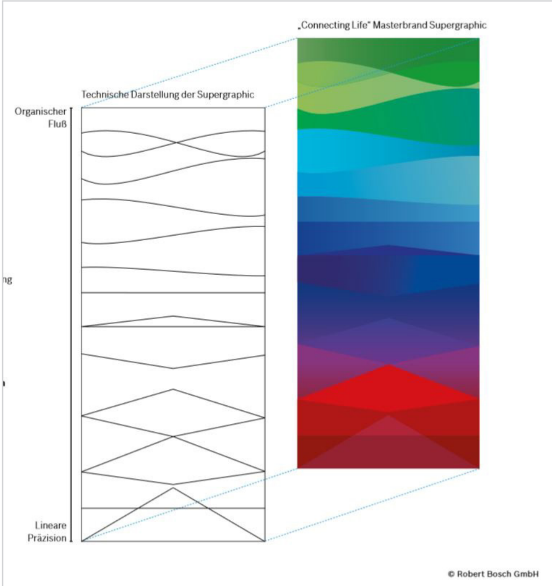


Figure 78 - Super-graphic (Bosch, 2016)

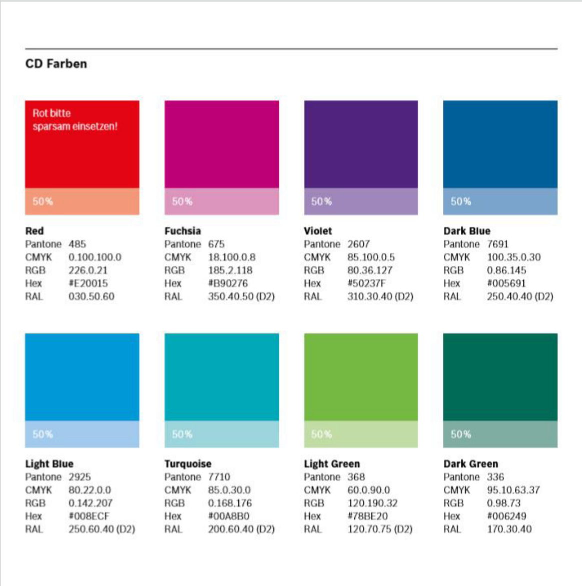


Figure 79 - Colour spectrum (Bosch, 2016)

The suggested product name is **AGRI SENSE** and the logo (Figure 80) has a green colour, which is associated to the natural farmers' environment. In print materials, the colour white and gray can be also used.

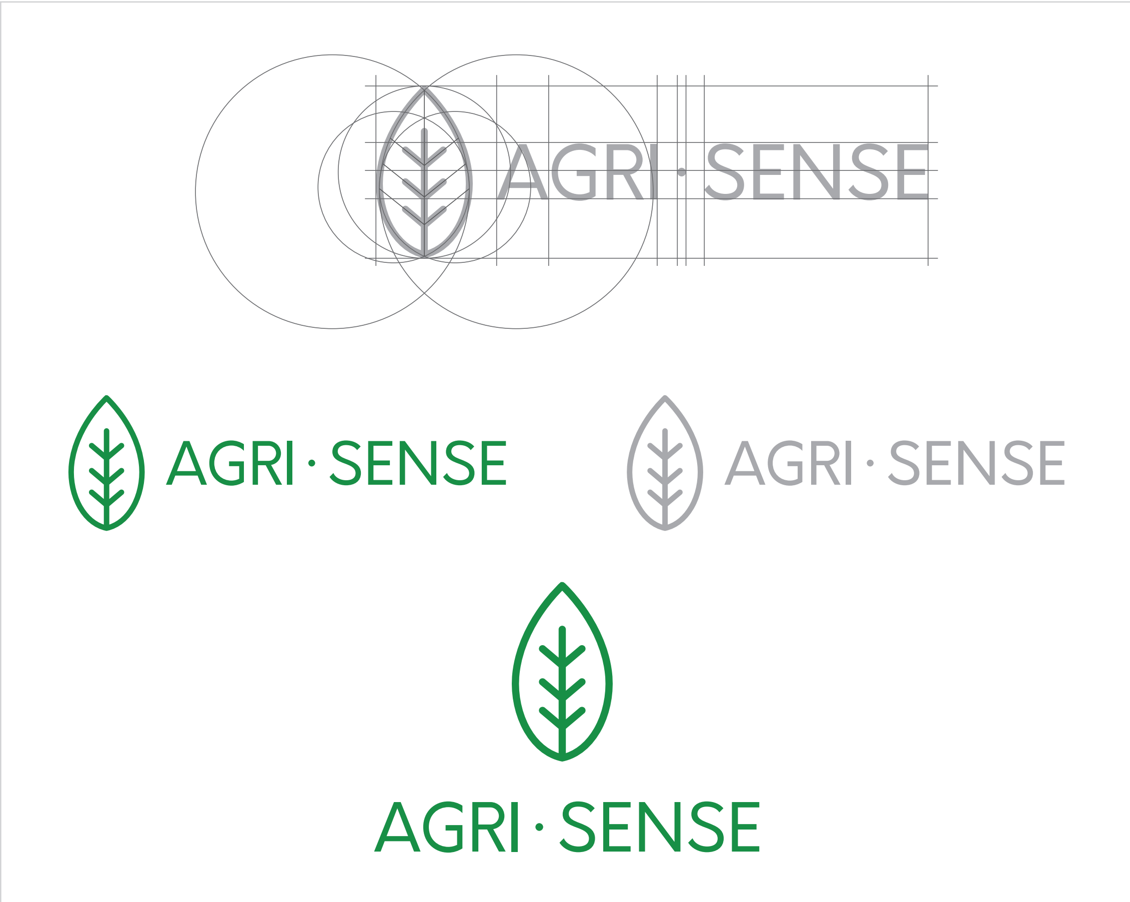


Figure 80 - Suggested logo

Figure 81 - Device in real environment

Figure 82 - Print advertisement suggestion

Figure 83 - Print advertisement suggestion

The following packaging is proposed for being placed on the market for sale. The packaging is also inspired by the new Bosch packaging design (Figure 84).

Figure 84 - New packaging line

Figures 85 - Packaging suggestion

Figures 86 - Packaging suggestion

CHAPTER SIX

CONCLUSIONS AND CRITICAL EVALUATION

1 A NEW DEVICE AND AN OPEN FIELD

2 FINAL CONSIDERATIONS

3 FUTURE RECOMMENDATIONS

1 A new device and an open field

This Final Project Work drew on two projects previously realized by Bosch, whose objective was to discover new opportunities for helping farmers improve the yield production. The quantity and quality of information provided by Bosch was crucial for achieving the goal of creating a sensor device for agriculture. Although it was clear and concrete that the outcome of this Final Project Work would be a sensor device, it was proven to be even so challenging and complex. Creating empathy for the users without having participated actively on the field research is very challenging, but as soon as it is possible to be immersed on their environment and aspirations, the motivation to provide farmers a better experience grows increasingly. This process of trying to understand deeply the persons we design for is very rewarding, inasmuch as people tend to open up more when they realize our attempt to create with them and not only for them.

Thanks to the designer experience with human-centered methods, hardly effort was necessary to accomplish the tasks, considering that the methods at issue are not simple and it needs time to become acquaint with the procedure. However, as much as there are forces that can influence the success of a project, there are also aspects that cannot be predicted or controlled and might have influence on the project course. For instance, even though many concepts have been presented previously to the farmers, revealing their preference to sensor devices, it would have been interesting to present them the current concepts, and clarify, i.e., if modules with different sizes are more appealing than just one size. Such details can be considered of secondary importance, but can provide a more solid result at the end. Due to legal and financial matters at the company, a final meeting with farmers was lacking. Notwithstanding, the support and expertise of the team at the company was essential to get to the final result. The sensor device has a compact and simple form and therefore not intimidating. Eliminating cables and compressing three components into one helps to “hide” the complexity of the device, since the user is not interested about dealing with high technological demands. For the benefit from Bosch, the device is now a product that can be recognized as from the family, since colours and design elements made a point of being implemented accordingly.

Further tests and likely improvements are necessary to further development, since prototype testing is a must, prior to any market introduction. This Final Project Work leaves Bosch and readers with a device that reflects the possibility of creating high technological products that are simple and anyway show quality and reliability.

2 Final considerations

In order to guide this Final Project Work, research questions were imposed and accordingly answered in its course.

How designers can overcome design quality issues?

By incorporating a human-centered design approach it is possible to create not only a positive experience for people we design, but also avoiding surprises when the product is already in the market. Companies that try in-market experimenting by testing and seeking feedback regarding market acceptance and possible design changes have more chance of quickly adapting to users' wishes. Moreover, creating empathy for users as well as involving them in the process increases the opportunity of creating innovative products.

Why sensor technology is important for agriculture?

Farmers are the experts when it comes to know-how, however, there are many factors in the nature that can not be controlled nor measured by humans. These factors, such as temperature change, have a massive influence on yield production and, if not handled, it can result in crop losses that cannot be afforded in the future. Sensors help farmers to deal with environmental conditions, enhancing their farm management and consequently improving the yield.

What are the farmers' needs towards sensor devices?

Farmers are open to new technologies and experiments, and they see potential in sensor devices as they realized their importance. However, many of them have had bad experience with sensors so far, as they do not adapt to their needs. Those needs include devices that are robust, as there were many reports of their frustration with devices that were broken after a short time; devices that are easy to install and handle; needs for having a device that does not hinder their daily work; an adaptable and flexible device; the fear of becoming an office-farmer and how they enjoy building and fixing by their own.

Why people are reluctant of buying smart devices?

People get scared when they see huge instruction manuals and frustrated about the time spent on installing and trying to understand how the product works. The complexity of understanding how Big Data works and what companies are doing with their data are time-consuming, additionally to the fear of having machines controlling their lives and houses, are retarding the mass-adoption of such technologies. However, many consumers are open for trials and are forcing the market to adapt to their needs.

How to address the users' needs on modern devices?

By gathering in-depth understanding about user's habits, perceptions, desires and context, not only at the beginning from the project but along the whole way. Letting users participate on the process has also proven to be vital in preventing mistakes and therefore designing *good* products.

What both studies carried by Bosch provide for this Final Project Work?

A massive amount of valuable information about users and their environment, and the most important, the users' wish towards a sensor device that is universal and adaptable to their way of working. The studies provided strong motivation and inspired imagination through dynamic tools and methods.

How a human-centered design approach can help on the development of successful devices?

Many authors mentioned in this Final Project Work agree that a human-centered design approach contributes to the success of a product. It seems obvious that a company should know the consumer for whom they are designing, but this is not always pragmatically applied. There is a mind-set of introducing user experience more than just in the design process, but also in the whole company. Bosch is already setting this attitude by creating UX department in every sector of the company. The environment is great and very dynamic; people get more motivated and, why not, more creative. A human-centered approach is not limited to design and can be very useful in every field.

3 Future recommendations

This Final Project Work has introduced the development of a smart device considering users' wishes and motivations. Nonetheless, there are certain aspects to be considered in the future. Although it is understandable that such a device needs to balance financial and manufacturing aspects, a deeper research on technical specifications would be desirable. For instance, the future of power for IoT devices is rapidly developing and there are many new approaches that have high potential of becoming the best and most efficient way of power supply. Energy harvesting e.g. is according to many articles (see Sekine, 2016; Schweber, 2016; Bush, 2016) very promising and could be also the chance for a finally acceptance of IoT devices. However, since it is a very new approach, it might be necessary to wait for a more concrete knowledge and further reduction of the energy consumption of IoT devices. Regardless, there is a need of being more open about new trends and of giving a chance by thoroughly analysing it and perhaps trying it. Furthermore, through this research project, it became clear that there is a wish for having smaller devices; however, this wish is prompted by the fact that many devices are either not fulfilling their goals, or even worse, disturbing their environment. People want smart devices, but only as long as they are working like expected. If this is not the case, it might influence the user's next purchase as a bad experience has sometimes more impact than a good one. Even though devices do not need to be smaller to be good, for the future would be advantageous to search for new possibilities of reducing size, by designing technical components specially for the device, instead of purchasing a manufactured one.

The concept here presented, focused more on the device that is placed in the soil, by concentrating in providing a solution for adapting the height and depth of the sensor device with a modular concept and compacting the device. Furthermore, the device meets Bosch business model, as its components can be used separately as well. However, as the focus laid more on the sensor device for the soil, it might be desirable to look in the future for other possible solutions, e.g., for hanging the device on the tree. Now the device provides a hole where it is possible to tied a cable to the tree, but it certainly exists more options that need to be studied before putting into practice. Hence, it became clear that it is a challenge to encompass all the aspects involved, but beyond that, this project opened the way for significant breakthroughs.

Besides, it also proves that it is possible to design a simple and user-friendly device by carrying user testings, considering design principles as well as the interdisciplinarity of a company during the whole process. Moreover, the agricultural industry offers a lot of opportunities for the design and development of future machinery and devices, as long as companies are willing to include their wishes and motivations into new solutions. Finally, the more designers and researchers work together, the more is the chance to come up with great innovations.

REFERENCES

Books, chapters or publications

Accenture (2014a). Big Success With Big Data: Executive Summary. Chicago, IL: Accenture. [online] Available at: https://www.accenture.com/be-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Industries_14/Accenture-Big-Data-POV.pdf [Accessed 14 Aug. 2016].

Accenture (2014b). The Internet of Things: The Future of Consumer Adoption. Chicago, IL: Accenture. [online] Available at: https://www.accenture.com/t20150624T211456__w__/us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Technology_9/Accenture-Internet-Things.pdf [Accessed 14 Aug. 2016].

Accenture (2014c). Engaging the Digital Consumer in the New Connected World. Chicago, IL: Accenture. [online] Available at: https://www.accenture.com/us-en/~/media/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Dualpub_7/Accenture-Engaging-Digital-Consumer-New-Connected-World.pdf [Accessed 18 Jul. 2016].

Accenture (2015a). Digital Business Era: Stretch Your Boundaries. Chicago, IL: Accenture. [online] Available at: https://www.accenture.com/t20160321T213110__w__/us-en/_acnmedia/Accenture/pdf/Accenture-Technology-Vision-for-Pega-2015_080615.pdf [Accessed 14 Jul. 2016].

Accenture (2015b). Smart Production: Finding a Way Forward. How Manufacturers Can Make the Most of the Industrial Internet of Things. Chicago, IL: Accenture. [online] Available at: https://www.accenture.com/t20160119T041002__w__/us-en/_acnmedia/PDF-5/Accenture-804893-Smart-Production-POV-Final.pdf [Accessed 14 Aug. 2016].

Accenture, (2016). People First: The Primacy of People in a Digital Age. Chicago, IL: Accenture. [online] Available at: https://www.accenture.com/t20160314T114937__w__/us-en/_acnmedia/Accenture/Omobono/TechnologyVision/pdf/Technology-Trends-Technology-Vision-2016.PDF [Accessed 20 Sep. 2016].

AIOTI, Alliance for Internet of Things Innovation (2015). Smart Farming and Food Safety Internet of Things Applications: Challenges for Large Scale Implementations. Brussels: European Commission. [online] Available at: https://ec.europa.eu/programmes/horizon2020/en/news/open-day-iot-large-scale-pilot-smart-farming-and-food-security [Accessed 30 Jun. 2016].

Battarbee, K., Suri, J. F., and Howard, S. G. (2013). Empathy on the Edge: Scaling and Sustaining a Human-Centered Approach in the Evolving Practice of Design. Palo Alto, CA: IDEO. [online] Available at: http://5a5f89b8e10a225a44ac-ccbed124c38c4f7a3066210c073e7d55.r9.cf1.rackcdn.com/files/pdfs/news/Empathy_on_the_Edge.pdf [Accessed 15 Jul. 2016].

Beecham Research, (2014). Towards Smart Farming: Agriculture Embracing the IoT Vision. Boston, MA: Beechman Research. [online] Available at: https://www.beechamresearch.com/files/BRL%20Smart%20Farming%20Executive%20Summary.pdf [Accessed 28 Jun. 2016].

Beechman Research (2016). The Future of Farming Through the IoT Perspective. Boston, MA: Beechman Research. [online] Available at: http://www.beechamresearch.com/download.aspx?id=1051 [Accessed 11 Jul. 2016].

Beyer, H., and Holtzblatt, K. (1997). Contextual Design: A Customer-Centered Approach to Systems Designs. San Francisco, CA: Morgan Kaufman Publishers.

Boeijen, A., Daalhuizen, J., Zijlstra, J. and Schoor, R. (2014). Delft design guide.

Borja de Mozota, B. (2003). Design Management: Using Design to Build Brand Value and Corporate Innovation. Skyhorse Publishing Inc.

Bosch (2016). "Bosch Design Guideline". Gerlingen: Bosch, unpublished document.

Diamond, J. (1997). Guns, Germs, and Steel: The Fates of Human Societies. New York: W.W. Norton & Co.

Dreyfuss, H. (1955). Designing for People. New York: Simon & Schuster.

European Union (2014). Precision Agriculture: An Opportunity for EU Farmers - Potential support with the CAP 2014-2020. Luxembourg: European Parlament.

FAO (2009). "Global agriculture towards 2050". High Level Expert Forum: How to Feed the World in 2050, Rome: FAO.[online] Available at: http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf [Accessed 30 Jun. 2016].

Greenbaum, J., and Kyng, M. (eds) (1991). Design at Work: Cooperative Design of Computer Systems. Hillsdale, NJ: LEA.

GSMA (2015). GSMA: The Impact of the Internet of Things: The Connected Home. London: GSMA. [online] Available at: http://www.gsma.com/newsroom/wp-content/uploads/15625-Connected-Living-Report.pdf [Accessed 20 Sep. 2016].

IDEO (2011). Human-Centered Design ToolKit. Palo Alto, CA: IDEO.

Kimmel, A. J. (2015). People and Products: Consumer Behavior and Product Design. New York: Routledge.

Martin, K., and Sauerborn, J. (2013). Agroecology. New York: Springer.

Mazoyer, M., and Roudart, L. (2006). A History of World Agriculture: From the Neolithic Age to the Current Crisis. New York: Montly Review Press.

National Research Council (1997). Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management. Washington, DC: National Research Council, National Academy Press.

Norman, D. (2013). The Design of Everyday Things: Revised and Expanded. New York: Basic Books.

O'Grady, J., and O'Grady, K. V. (2000). A Designer's Research Manual: Succeed in Design by Knowing Your Clients and What They Really Need. Gloucester, MA: Rockport Publishers.

Oliver, M., Bishop, T., and Marchant, B. (2013). Precision Agriculture for Sustainability and Environmental Protection. Abingdon, UK: Routledge.

Sanders, E. B.-N. (2000). "Generative tools for co-designing". In Scrivener, S. A.R., Ball, L. J., Woodcock, A. (eds), Collaborative Design. London: Springer Verlag, pp. 3-12.

Sanders, E. B.-N. (2013). “Perspectives on design in participation. In Mareis, C., Held, M., and Joost, G. (eds), Wer Gestaltet die Gestaltung? Praxis, Theorie und Geschichte des Partizipatorischen Designs. Berlin: Verlag.

Sanders, E. B.-N., and Stappers, P. J. (2014). Convivial Design Toolbox. Amsterdam: BIS.

Sundmaeker, H., Guillemin, P., Friess, P., Woelfflé, S., (eds) (2010). Vision and Challenges for Realising the Internet of Things. Brussels: European Commission.

The Consumer Goods Forum, Capgemini, and Intel (2016). Making the Connection: How the Internet of Things Engages Consumers and Benefits Business. The Consumer Goods Forum, Capgemini, and Intel.

Verizon (2016). State of the Market: Internet of Things 2016. New York: Verizon. [online] Available at: https://www.verizon.com/about/sites/default/files/state-of-the-internet-of-things-market-report-2016.pdf [Accessed 28 Jun. 2016].

Vermesan, O. and Friess, P., eds (2014). Internet of Things: From Research and Innovation to Market Development. Aalborg: River Publishers.

von Hippel, E. (1988). The Sources of Innovation. New York: Oxford University Press.

von Hippel, E. (2005). Democratizing Innovation. London: MIT Press.

Ulrich, K. T., and Eppinger, S. (2015). Product Design and Development. New York: McGraw-Hill Education.

Papers, articles or proceedings

Ashton, K. (2009). “That ‚Internet of Things‘ thing: In the real world, things matter more than ideas”. RFIDJournal, June 22. [online] Available at: http://www.rfidjournal.com/articles/view?4986 [Accessed 10 Aug. 2016].

Black, A. (1998). “Empathic design: User focused strategies for innovation“. Proceedings of the Conference on New Product Development , IBC Conferences. London, pp. 1-8.

Bosch (2014). “20140930_Bonirob_User_Research“. Gerlingen: Bosch, unpublished document.

Bosch (2015a). “20150925_Bonirob_additional_fruits_user_research_full_refined“. Gerlingen: Bosch, unpublished document.

Bosch (2015b). “160127_ BOSP_PAA_ioTS_test_presentation“. Gerlingen: Bosch, unpublished document.

Bosch (2015c) “150113_BOSP_BoniRob_presentation_final“. Gerlingen: Bosch, unpublished document.

Buchenau, M., and Suri, J. (2000). “Experience prototyping”. DIS ‚00 Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, New York, pp. 424-433.

Bunge, J. (2014). “Monsanto expects 2014 U.S. Approval for new soybean seeds“. The Wall Street Journal, 20 August. [online] Available at: http://www.wsj.com/articles/monsanto-expects-2014-u-s-approval-for-newsoybean-seeds-1408566263 [Accessed 14 Aug. 2016].

Bush, J. (2016). “IoT power needs mirror energy harvesting systems“. [online] Electronicspecifier.com. Available at: http://www.electronicspecifier.com/power/iot-power-needs-mirror-energy-harvesting-systems [Accessed 15 Jul. 2016].

Chhatpar, R. (2007). “Analytic enhancements to strategic decision-making: From the designer’s toolbox”. Design Management Review, Winter, pp. 28.35.

Cooper, R. (1994). “New products: The factors that drive success”. International Marketing Review, 11 (1), pp.60-76.

Cooper, R., and Kleinschmidt, E. (1987). “New products: What separates winners from losers?” Journal of Product Innovation Management, 4(3), pp.169-184.

Fedoroff, N. (2015). “Food in a future of 10 billion”. Agriculture & Food Security, 4 (11). [online] Available at: https://agricultureandfoodsecurity.biomedcentral.com/articles/10.1186/s40066-015-0031-7 [Accessed 30 Jun. 2016].

Foley, J. (2014). “A five-step plan to feed the world”. National Geographic, May. [online] Available at: http://www.nationalgeographic.com/foodfeatures/feeding-9-billion/ [Accessed 30 Jun. 2016].

Gartner (2014). “Gartner says a typical family home could contain more than 500 smart devices by 2022”. Stamford, CT: Gartner Newsroom. [online]. Available at: http://www.gartner.com/newsroom/id/2839717 [Accessed 10 Jul. 2016].

Gartner (2015). “Gartner says 6.4 billion connected”. Stamford, CT: Gartner Newsroom [online] Available at: http://www.gartner.com/newsroom/id/3165317 [Accessed 10 Jul. 2016].

Gibbs, S. (2016). “Nest learning thermostat third-gen: The simple, effective heating gadget“. The Guardian, 3 June. [online] Available at: https://www.theguardian.com/technology/2016/jun/03/google-nest-learning-thermostat-third-generation-home-gadget-smart-heating [Accessed 10 Jul. 2016].

Godfray, H., Beddington, J., Crute, I., Haddad, L., Lawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas, S., and Toulmin, C. (2010). “Food security: The challenge of feeding 9 billion people”. Science, 327 (5967), pp. 812-818.

Griepentrog, H. (2011). “Smart Farming: Operable solutions, requirements and techniques for tomorrow “. DLG [online] Available at: http://www.dlg.org/news_agriculture.html?&wb=%2FpublicArtikelDetail.do&artikelId=4942&kategorieId=1&spracheId=2&sub=2015dlg [Accessed 3 Jul. 2016].

Kobie, N. (2015). “Forget smart fridges: Here’s the kitchen tech you really want“.The Guardian, 12 August. [online] Available at: https://www.theguardian.com/technology/2015/aug/12/smart-fridgeskitchen-tech-internet-of-things [Accessed 9 Jul. 2016].

Kotler, P., and Rath, G. A. (1984). “Design: A powerful but neglected strategic tool”. Journal of Business Strategy, 5(2), pp.16-21.

Kumar, M., Townsend, J. D., and Vorhies, D. W. (2015). “Enhancing consumers‘ affection for a brand using product design”. Journal of Product Innovation Management, 32 (5), pp. 716-730.

Leonard, D. A., and Rayport, J. (1997). “Spark innovation through empathic design”. Harvard Business Review 75 (6), pp. 102–113.

Levy, S. (2013). “How Nest is creating the conscious home, one smart device at a time”. Wired, 17 December 2013. [online] Available at: http://www.wired.co.uk/article/where-there-is-smoke [Accessed 4 Jul 2016].

Lloyd, P., and Scott, P. (1994). “Discovering the design problem“. Design Studies, 15 (2), pp. 125-40.

McBratney, A., Whelan, B., Ancev, T., and Bouma, J. (2005). “Future directions of precision agriculture”. Precision Agriculture, 6 (1), pp. 7-23.

McDonagh, D., Goggin, N., and Squier, J. (2005). “Signs, symbols, and subjectivity: An alternative view of the visual“. Computers and Composition, 22, pp. 79–86.

Mumgaard, J. (2012). “How do you express a brand through product design?“. Product Design and Development, 6 August. [online] Available at: https://www.pddnet.com/news/2012/06/how-doyou-express-brand-through-product-design [Accessed 14 Jul. 2016].

Newman, J. (2015). “Right Now, The Internet Of Things Is Like The Internet Of The 1990s”. Fast Company, March. [online] Available at: https://www.fastcompany.com/3044375/sector-forecasting/the-future-of-the-internet-of-things-is-like-the-internet-of-the-1990s [Accessed 9 Jul. 2016].

Norman, D. (2005). “Human-centered design considered harmful”. Interactions, 12 (4), pp. 14-19.

Pierce, D. (2015). “The Internet of Things is everywhere, but it doesn’t rule yet”. Wired, 29 December. [online] Available at: https://www.wired.com/2015/12/this-year-was-almost-the-year-of-theinternet- of-things/ [Accessed 9 Jul. 2016].

Porter, M. E., and Heppelmann, J. E. (2014). „How smart, connected products are transforming competition“. Harvard Business Review, 92 (11), pp. 64–88.

Rothstein, P. (1999). “The re-emergence of ethnography in industrial design today”. In Chicago 99 Design Education Conference: Repeating the Future Proceedings. Chicago, IL: Industrial Designers of America, pp. 162-177.

Sanders, E. B.-N. (2006). “Design research in 2006”. Design Research Quarterly, I (1), September, pp. 1-8.

Sanders, L. (2008). “An evolving map of design practice and design research”. Interactions, XV (6), November-December, pp. 13-17.

Sanders, E. B.-N., and Stappers, P. J. (2008). “Co-creation and the new landscapes of design”. CoDesign, 1 (4), pp. 5-18.

Schweber, B. (2016). “Options for Powering Your Wireless IoT Device“. [online] Digikey. Available at: http://www.digikey.com/en/articles/techzone/2016/apr/options-for-powering-your-wireless-iot-device [Accessed 13 Aug. 2016].

Sekine, K. (2016). “Energy-harvesting devices replace batteries in IoT sensors “. Core & Code. [online] Available at: http://core.spansion.com/article/energy-harvesting-devicesreplace-batteries-in-iot-sensors/#.WAKe9hZkge2 [Accessed 9 Aug. 2016].

Sleeswijk Visser, F., Stappers, P.J., van der Lugt, R., and Sanders, E. B.-N. (2005). ”Contextmapping: Experiences from practice”. CoDesign 1 (2), pp. 119-149.

Stompff, G. (2003). “The forgotten bond: Brand identity and product design”. Design Management Journal, 14 (1), pp.26-32

Suri, J. F. (2000). “Communicating with designers: The role of empathy, evidence and inspiration”. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 44 (38), pp. 795-798.

Suri, J. F. (2003). “The experience of evolution: Developments in design practice”. The Design Journal, 6 (2), pp.39-48.

Suri, J. (2008). “Informing our intuition: Design research for radical innovation”. Rotman Magazine, Winter, pp. 53-57.

Suri, J., and Marsh, M. (1997). “Human factors in design: Suggestions for effective communication in multi-disciplinary teams”. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 41 (1), pp. 460-464.

Suri, J. F., and Howard, S. G. (2006). “Going deeper, seeing further: Enhancing ethnographic interpretations to reveal more meaningful opportunities for design”. Journal of Advertising Research, 46 (3), pp.246-250.

Tey, Y., and Brindal, M. (2012). “Factors influencing the adoption of precision agricultural technologies: a review for policy implications”. Precision Agriculture, 13 (6), pp. 713-730.

Weisdorf, J. (2005). “From foraging to farming: Explaining the neolithic revolution”. Journal of Economic Surveys, 19(4), pp.561-586.

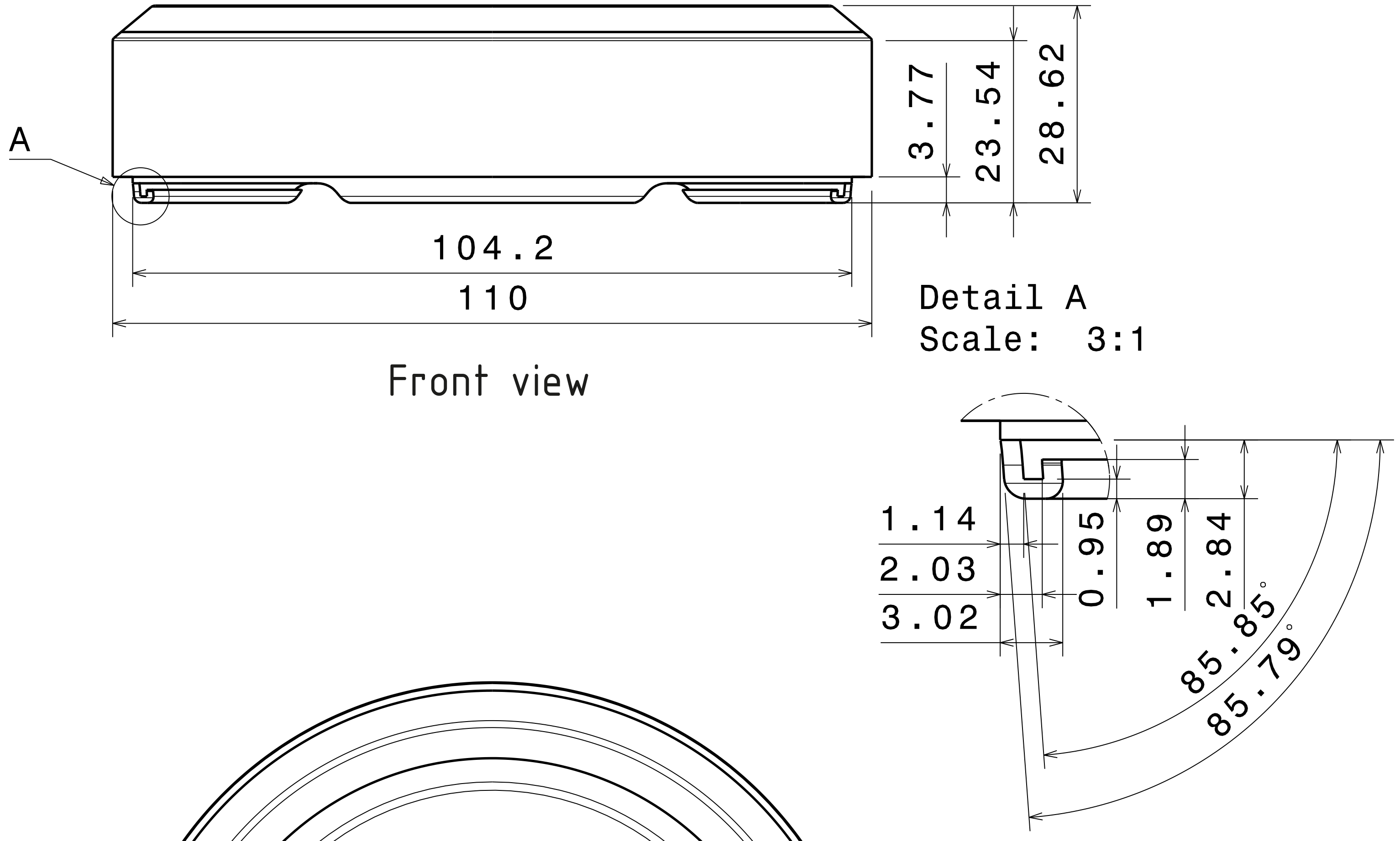
Welch, B., and Odegard, J. (2015). “Human-centered design: At the heart of a successful product development process“. Phillips-Medisize, Frederick Furness Publishing, pp.28-30. [online] Available at: http://www.ondrugdelivery.com/publications/57/Phillips_Medisize.pdf [Accessed 8 Aug. 2016].

Zirger, B. J., and Maidique, M. A. (1990). “A model of new product development: an empirical test “. Management Science, 36 (7), pp. 867-883.

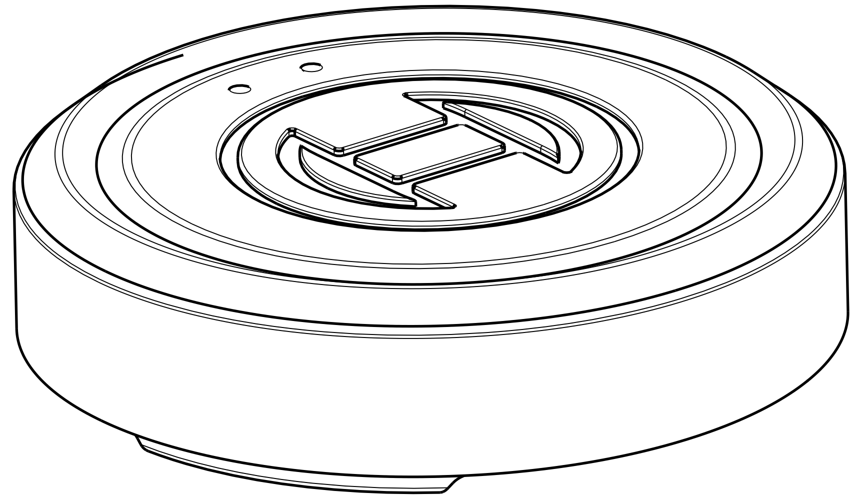
Videos

IBM (2015). The Internet of Things: How it works. IBM Big Data and Analytics Hub, Video. [ONLINE] Available at: https://www.youtube.com/watch?v=QSIPNhOiMoE [Accessed 5 March 2016].

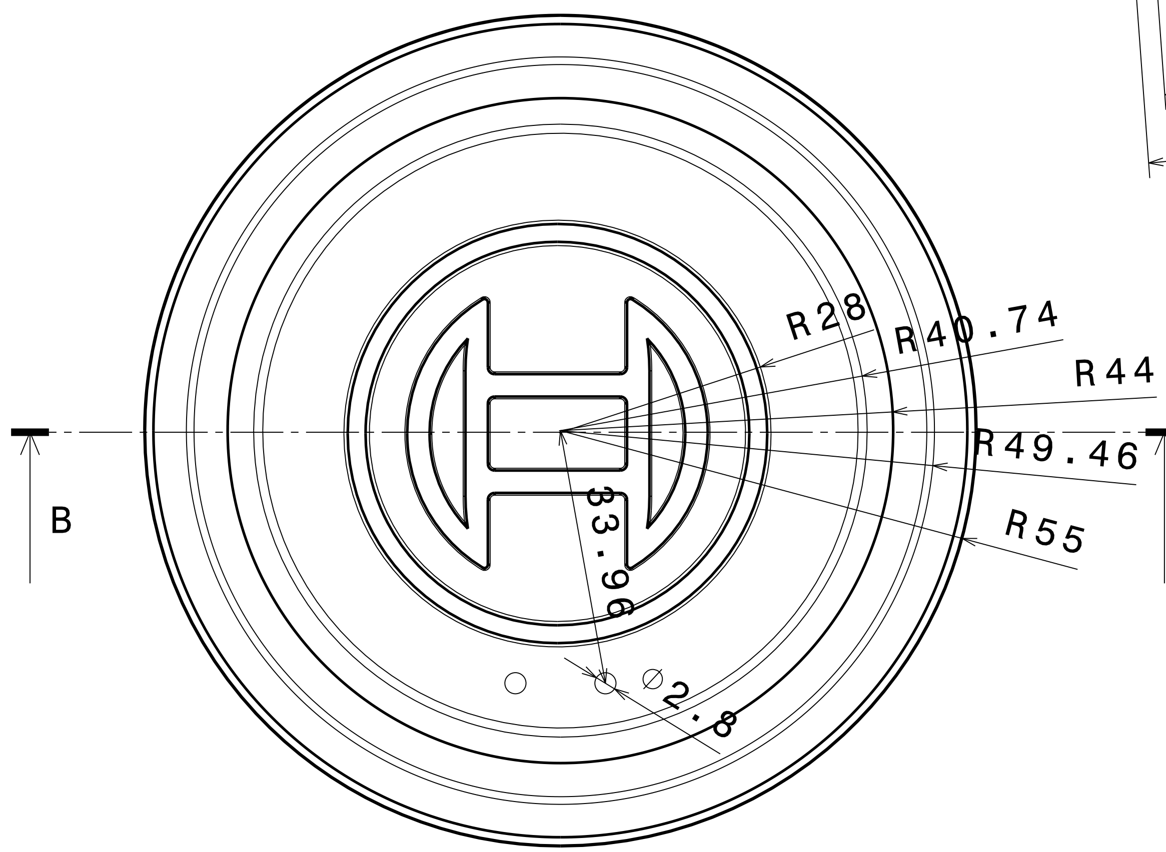
APPENDIX



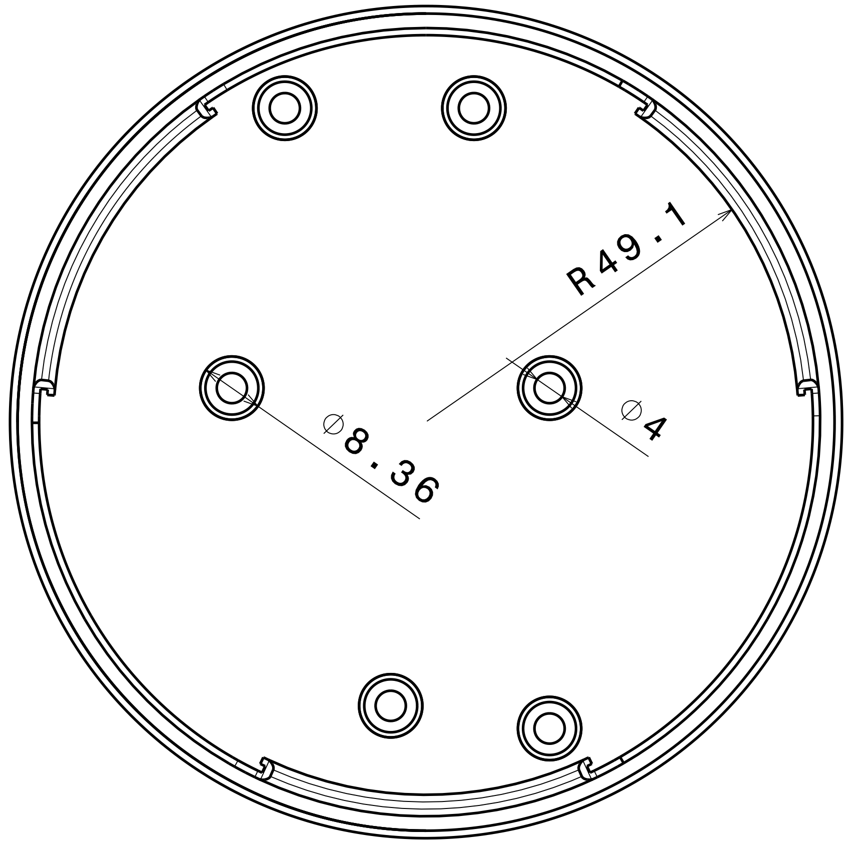
Front view



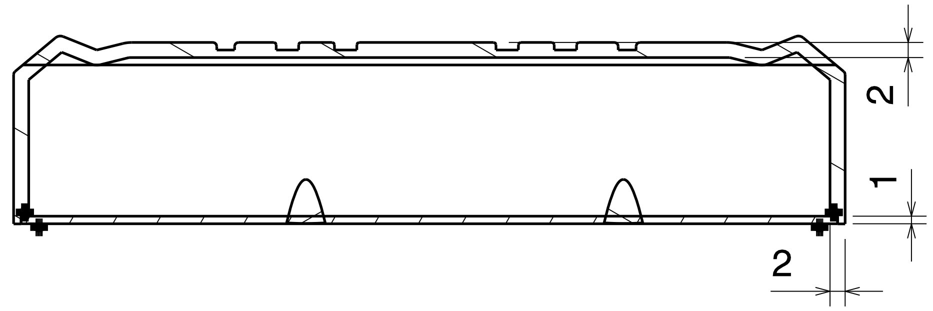
Isometric view



Top view

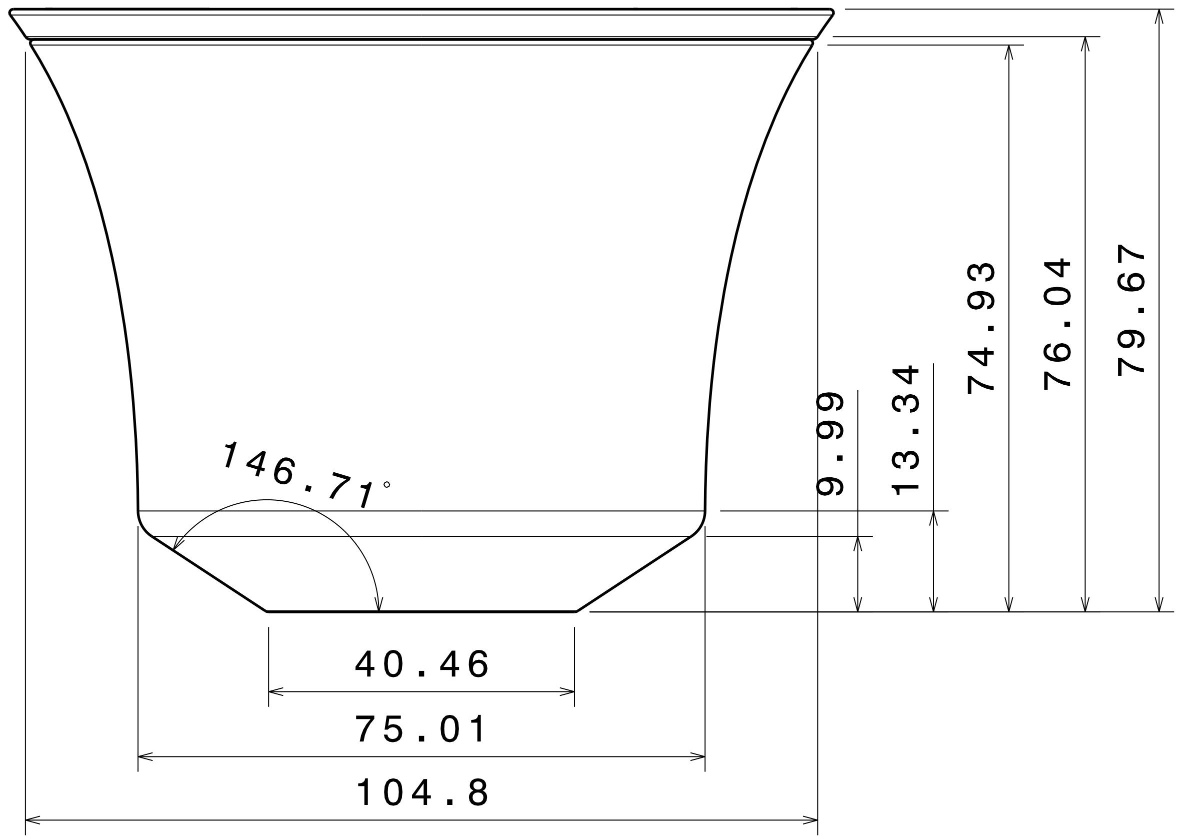


Bottom view

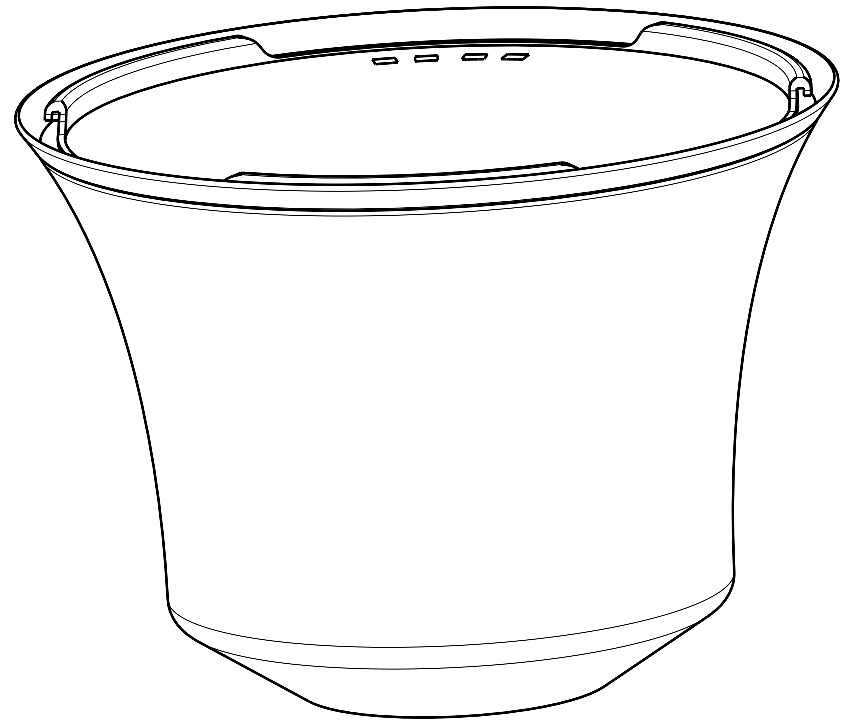


Section cut B-B

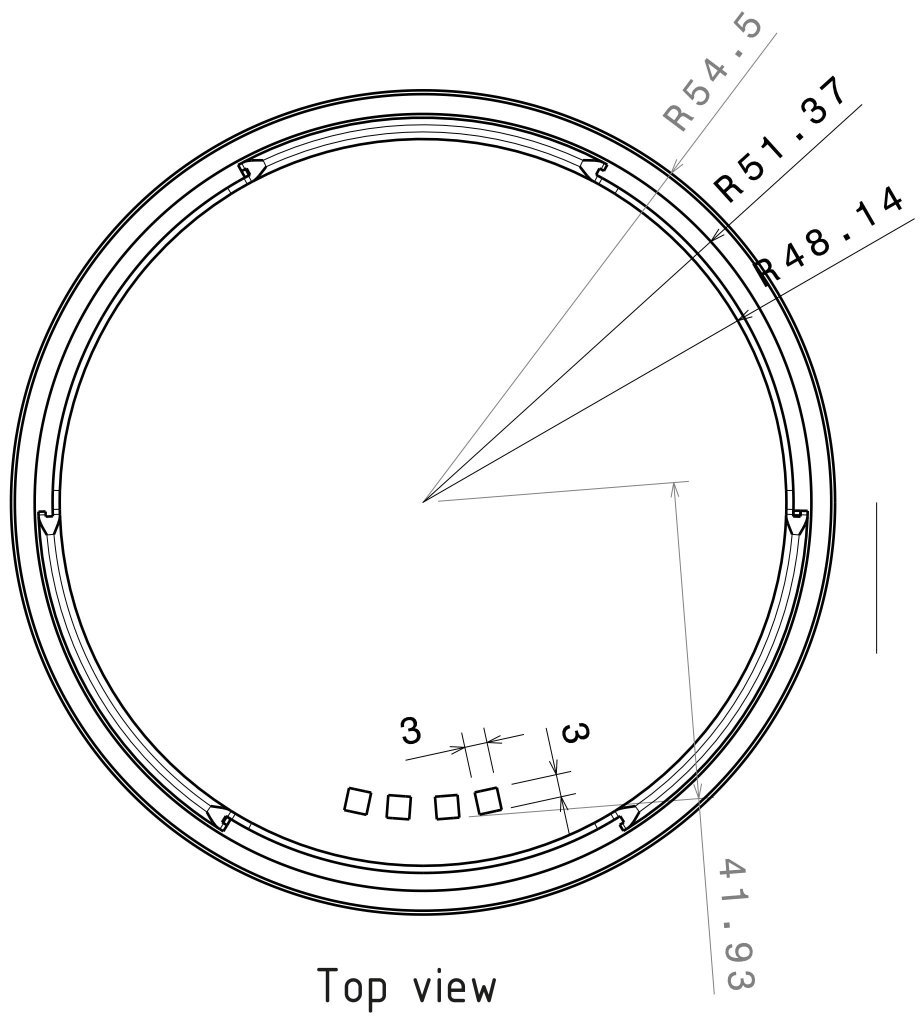
FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY: ADRIANE WASSMANSDORF MATTOS		MASTER IN PRODUCT DESIGN THESIS		
	TITLE: SENSOR DEVICE	DESCRIPTION: VIEWS and SECTION	ESCALA: 1:1	UNIDADE: mm	TAMANHO: A3
	PART: TOP CASE — N°: 1/1		REV.: B	DATA: 20.09.2016	FOLHA: 1/10



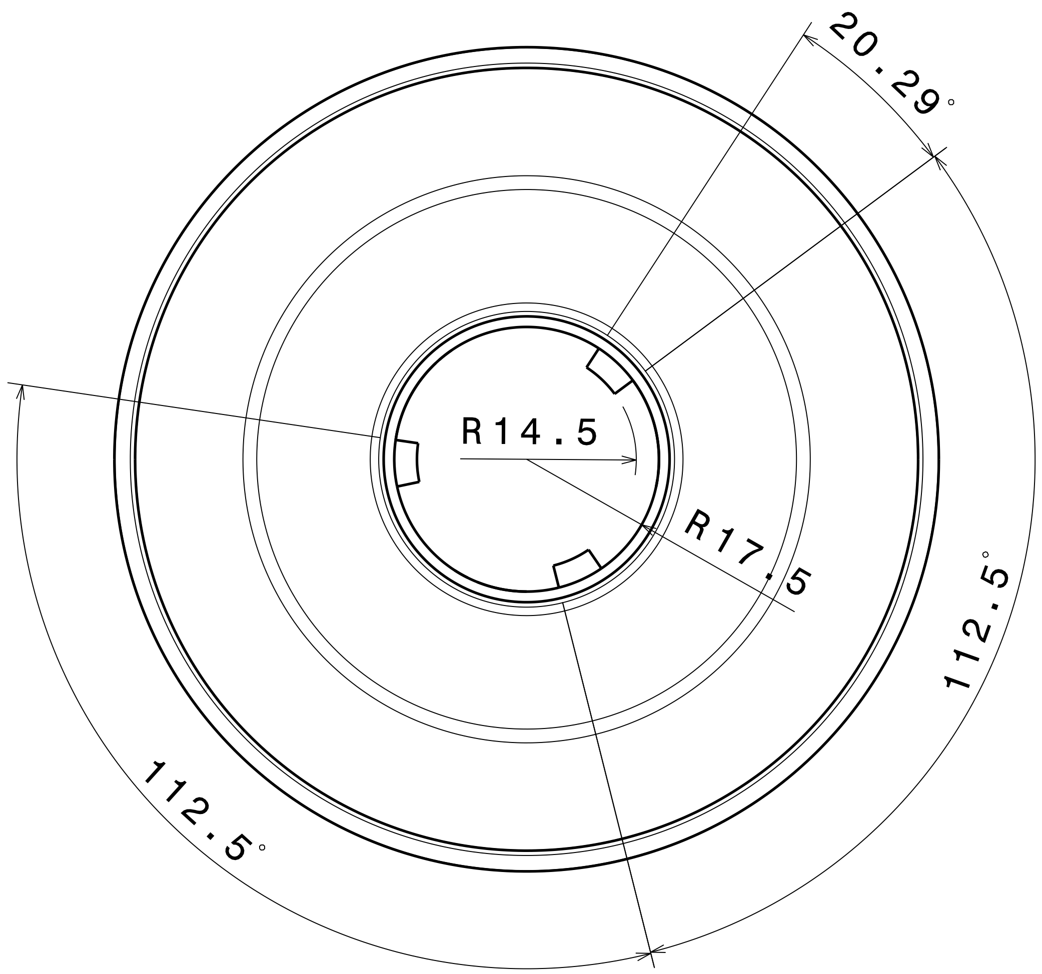
Front view



Isometric view

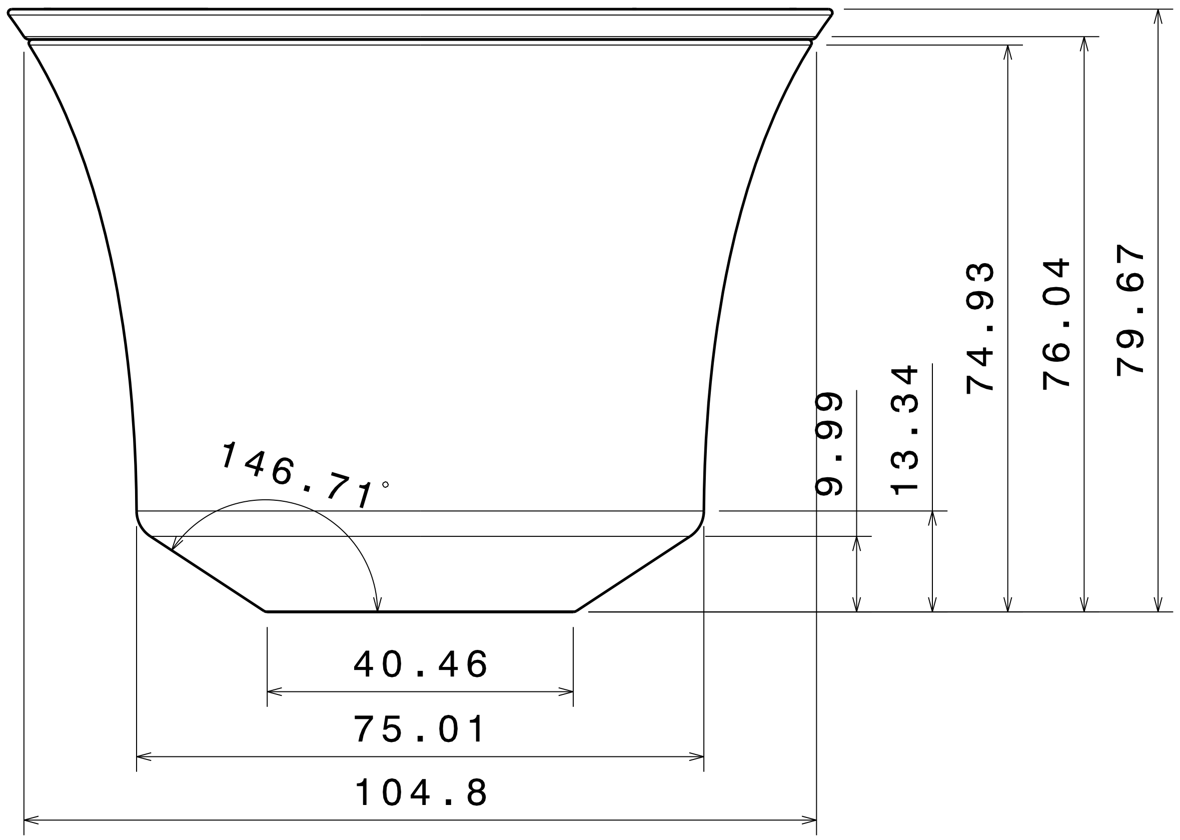


Top view

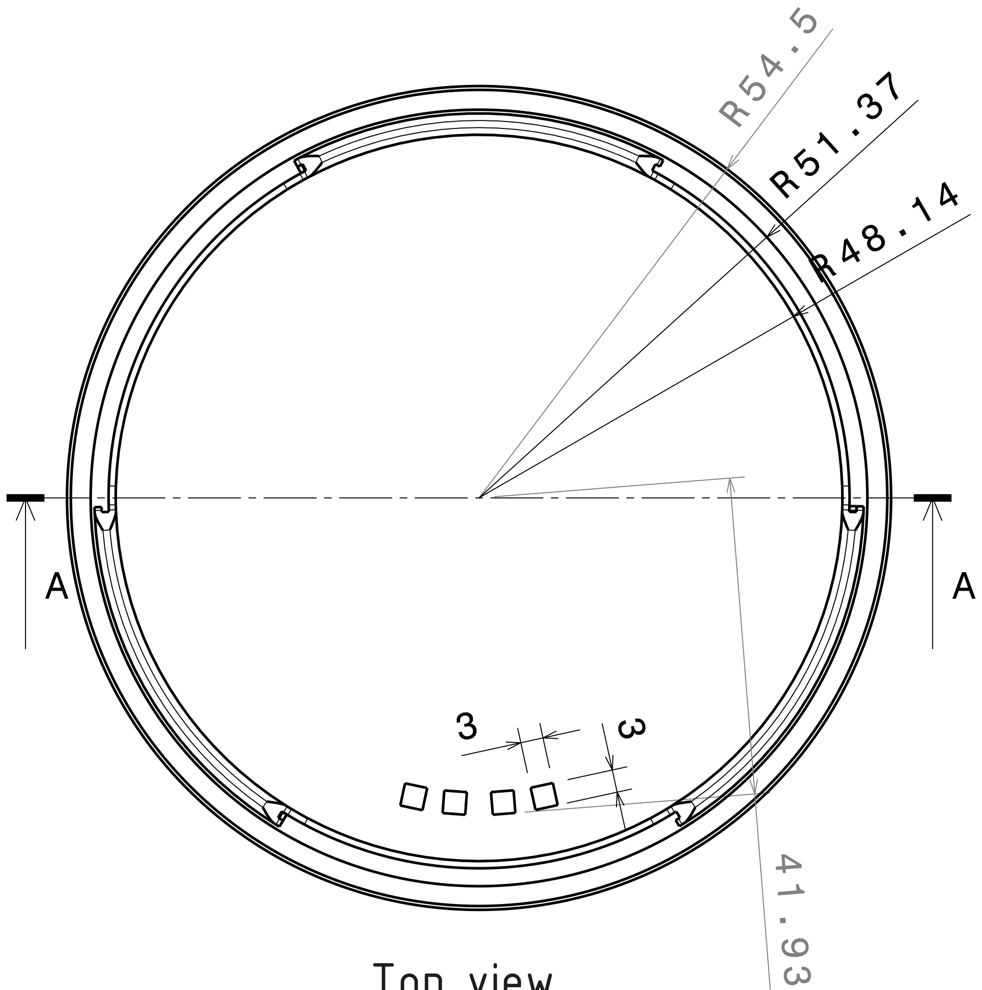


Bottom view

FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS			MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE		DESCRIPTION VIEWS	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART BOTTOM CASE	N° 1/2		REV. B	DATA 20.09.2016	FOLHA 2/10

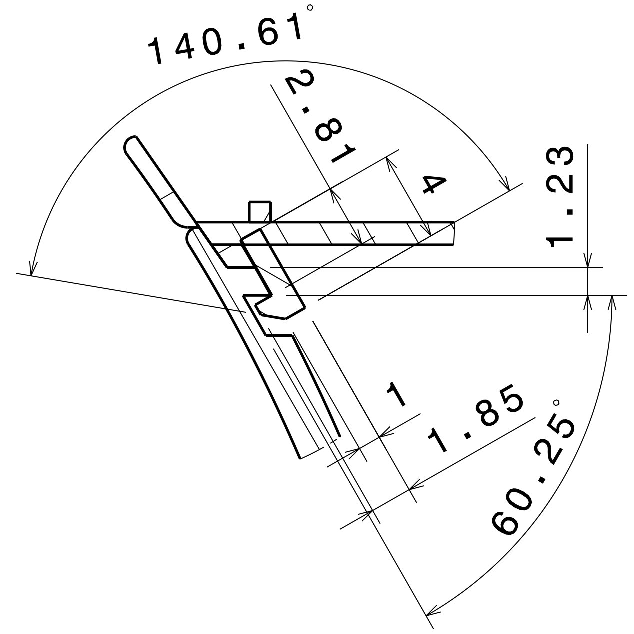


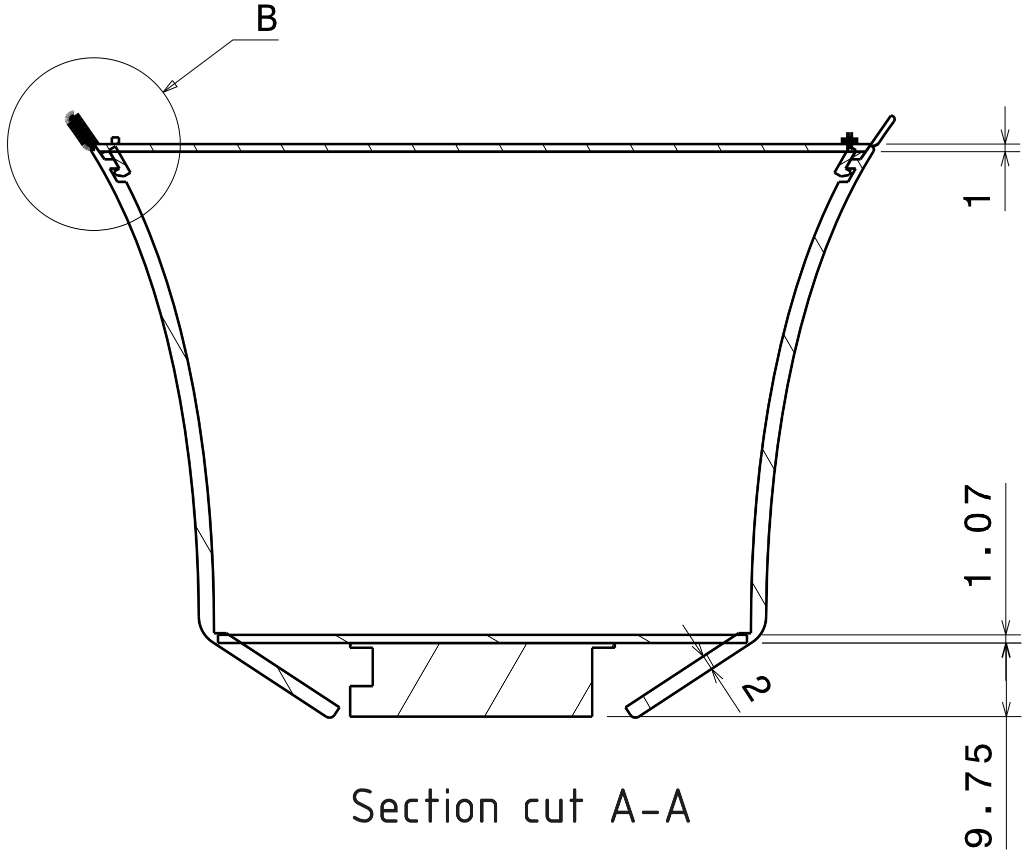
Front view



Top view

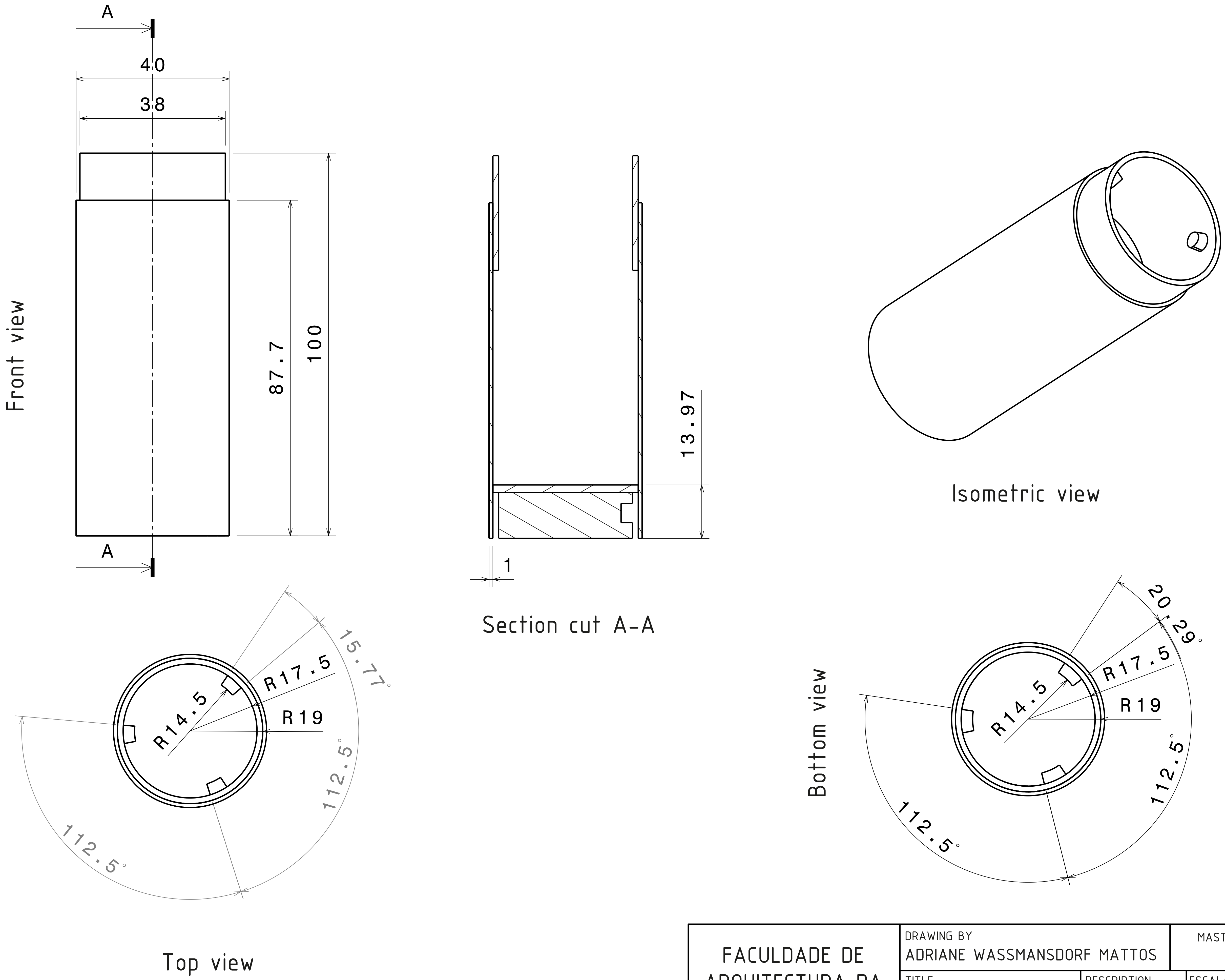
Detail B
Scale: 3:1



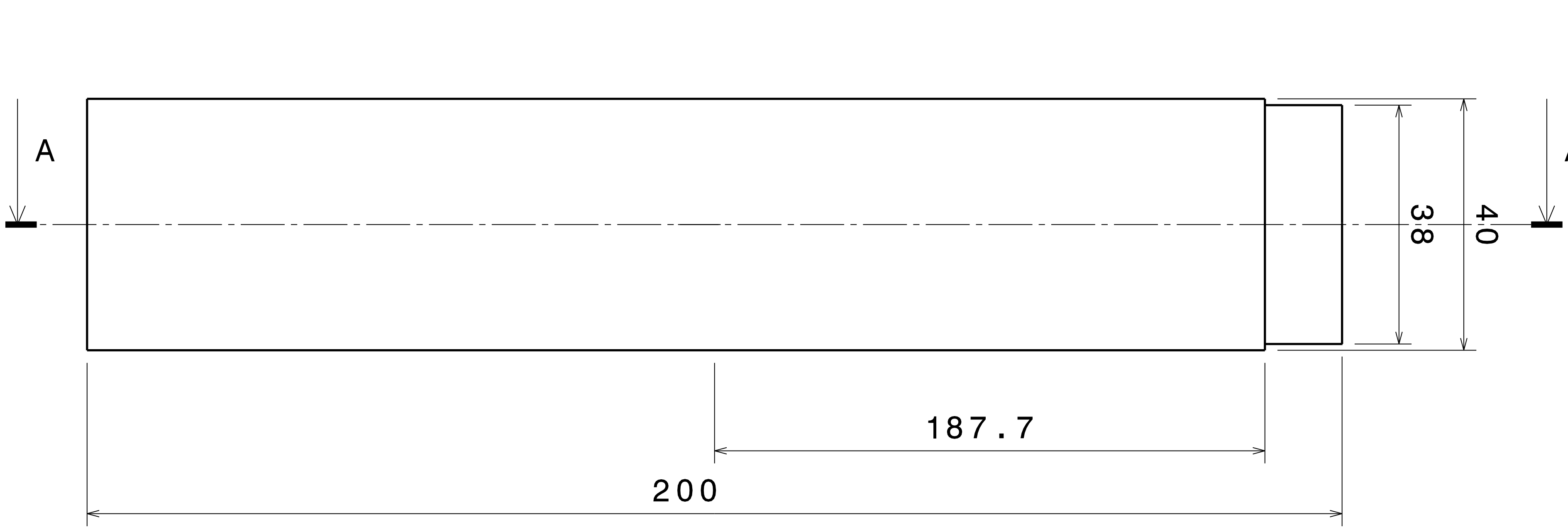


Section cut A-A

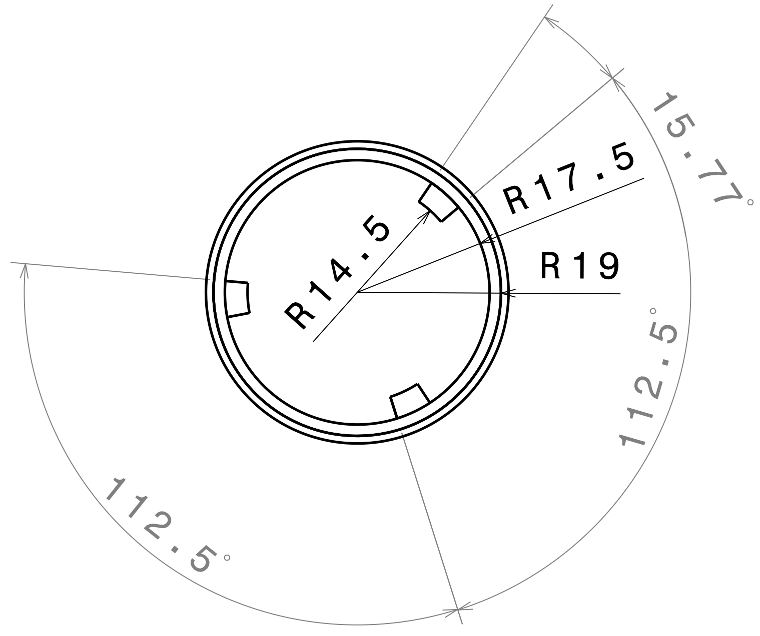
FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS			MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE		DESCRIPTION VIEWS and SECTION	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART BOTTOM CASE	N° 2/2		REV. B	DATA 20.09.2016	FOLHA 3/10



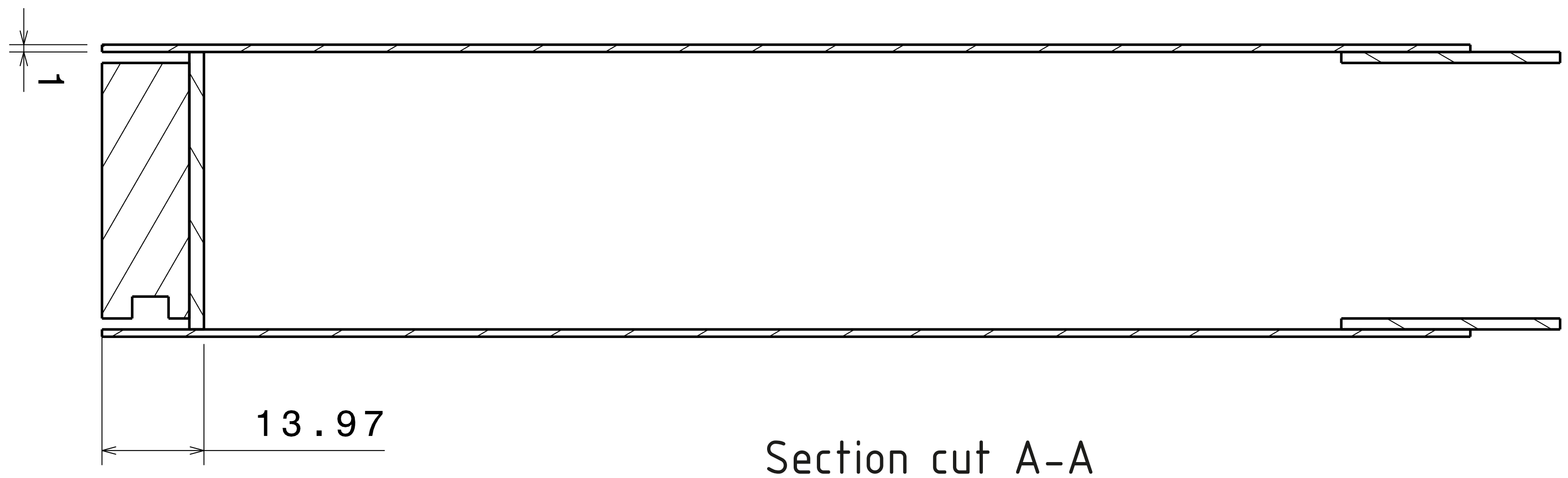
FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS			MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE		DESCRIPTION VIEWS	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART MODULE 1	Nº 1/1		REV. B	DATA 20.09.2016	FOLHA 4/10



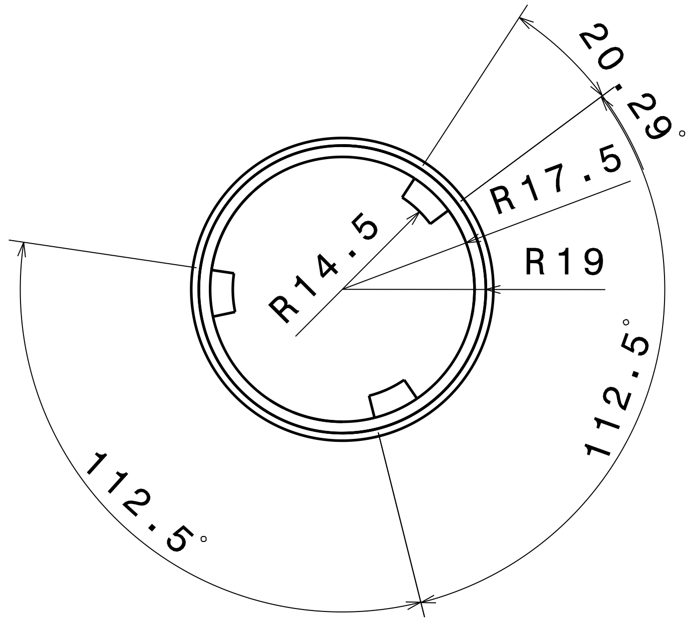
Front view



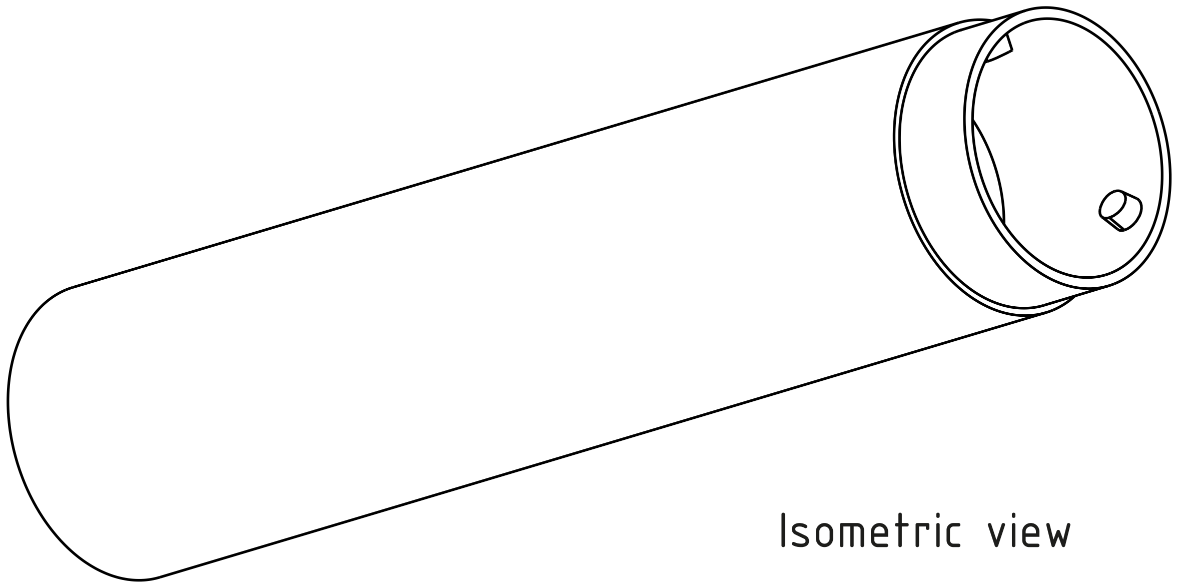
Top view



Section cut A-A

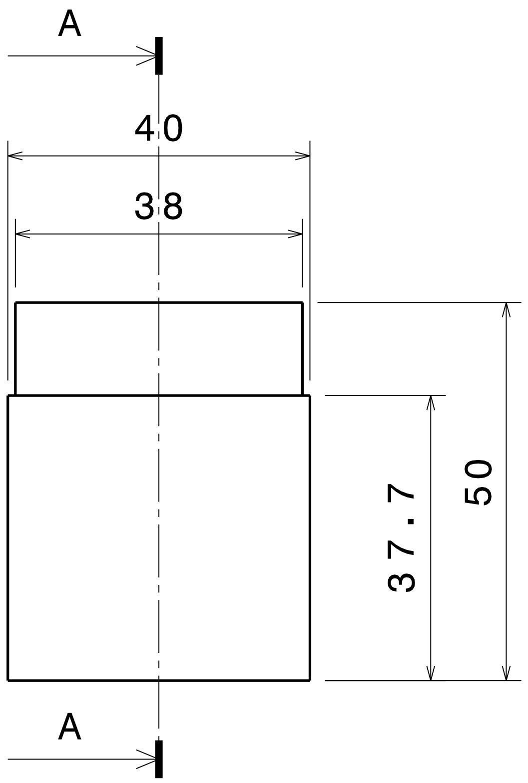


Bottom view

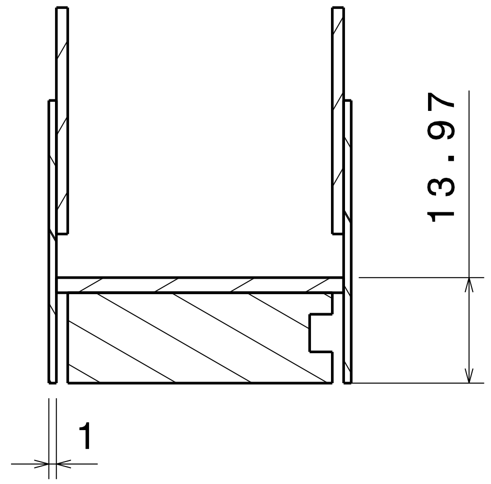


Isometric view

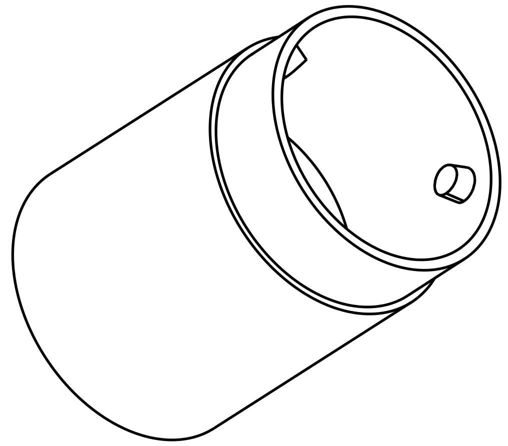
FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS			MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE		DESCRIPTION VIEWS and SECTION	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART MODULE 2	N° 1/1		REV. B	DATA 20.09.2016	FOLHA 5/10



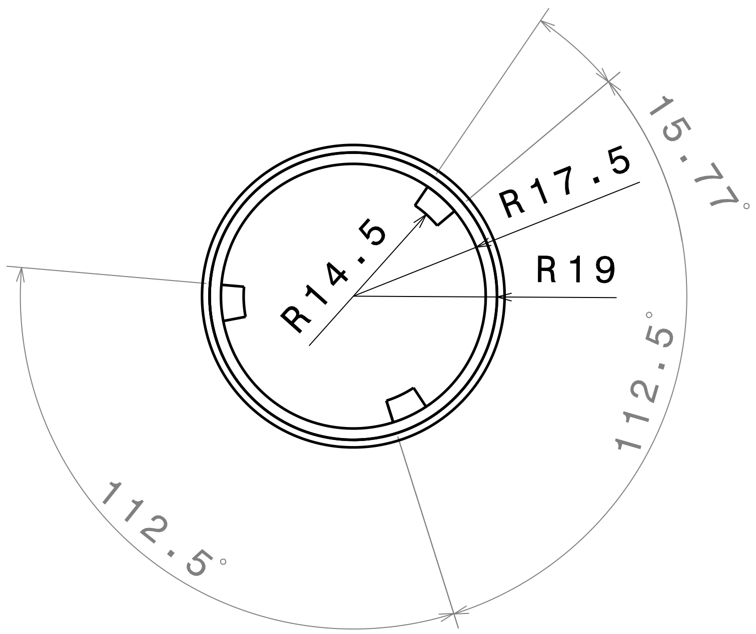
Front view



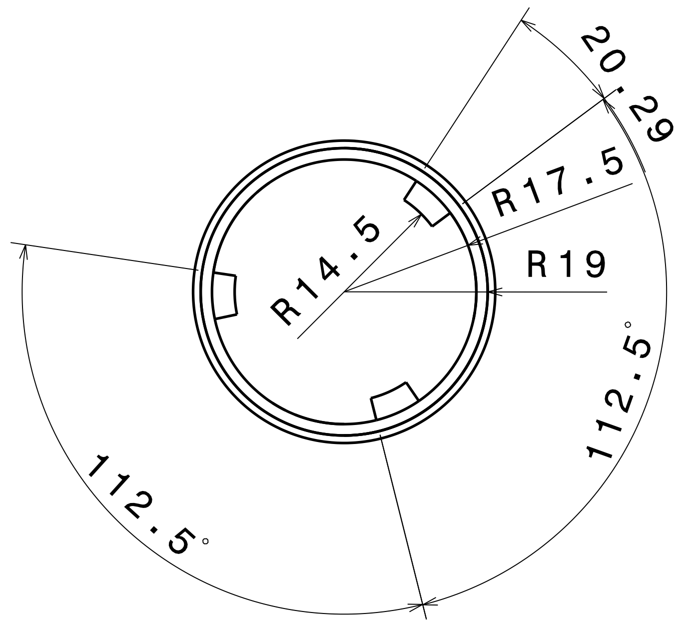
Section cut A-A



Isometric view



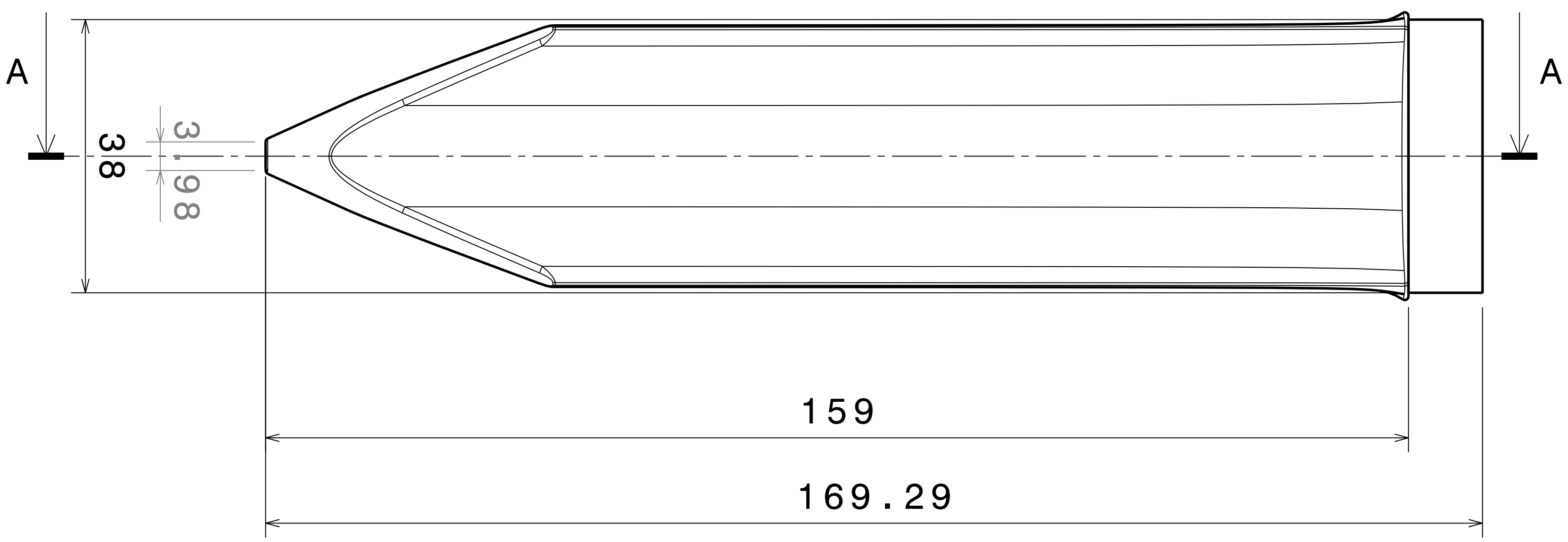
Top view



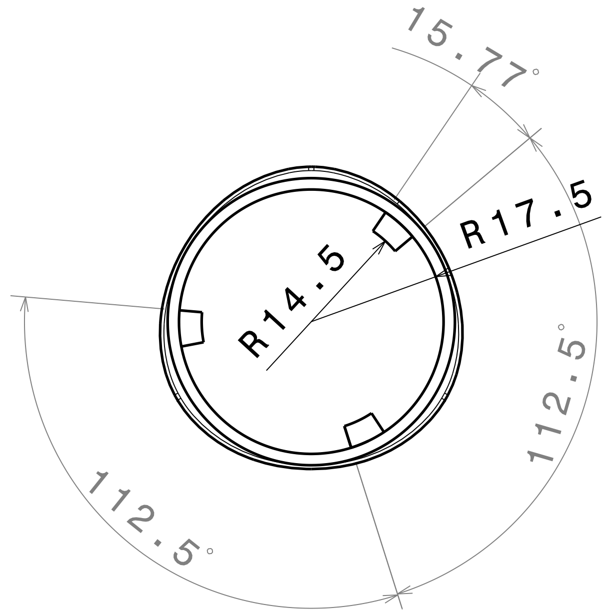
Bottom view

FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS			MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE		DESCRIPTION VIEWS and SECTION	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART MODULE 3	Nº 1/1		REV. B	DATA 20.09.2016	FOLHA 6/10

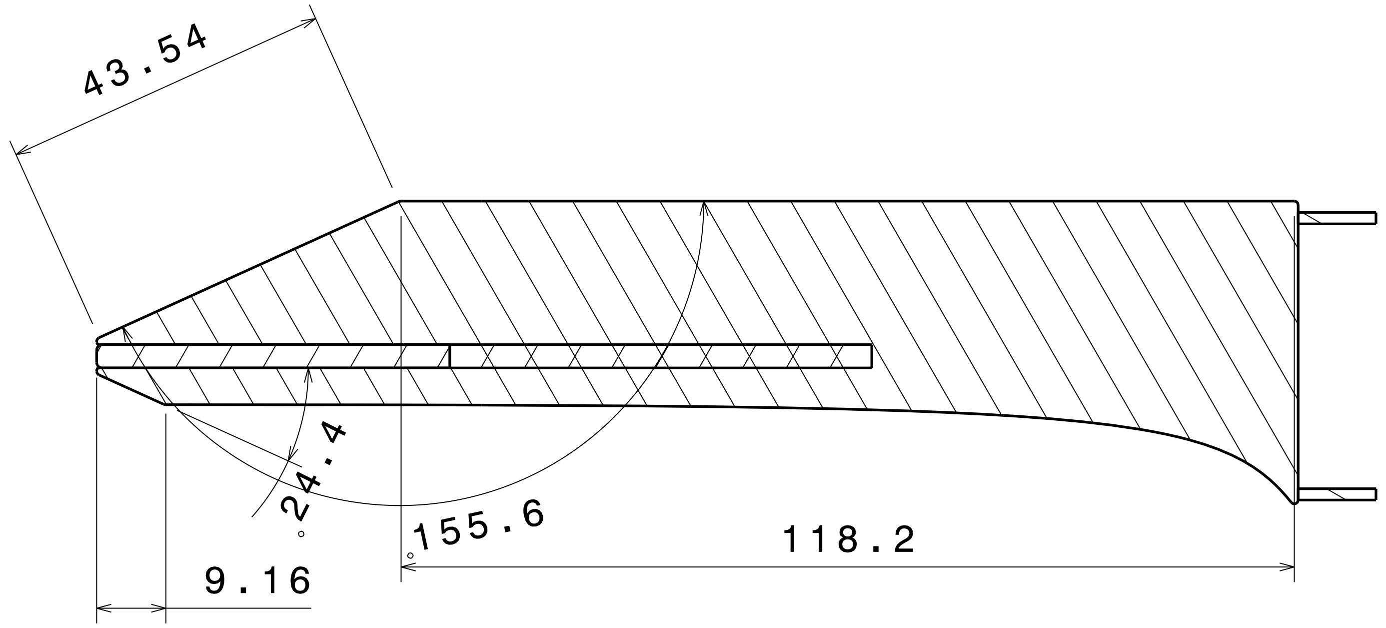
Front view



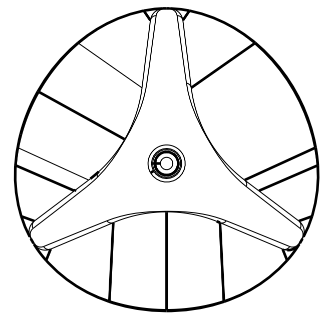
Top view



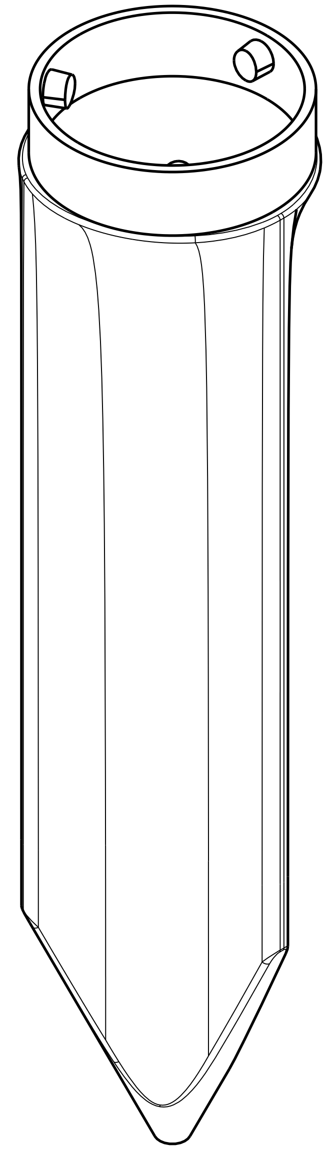
Section cut A-A



Bottom view



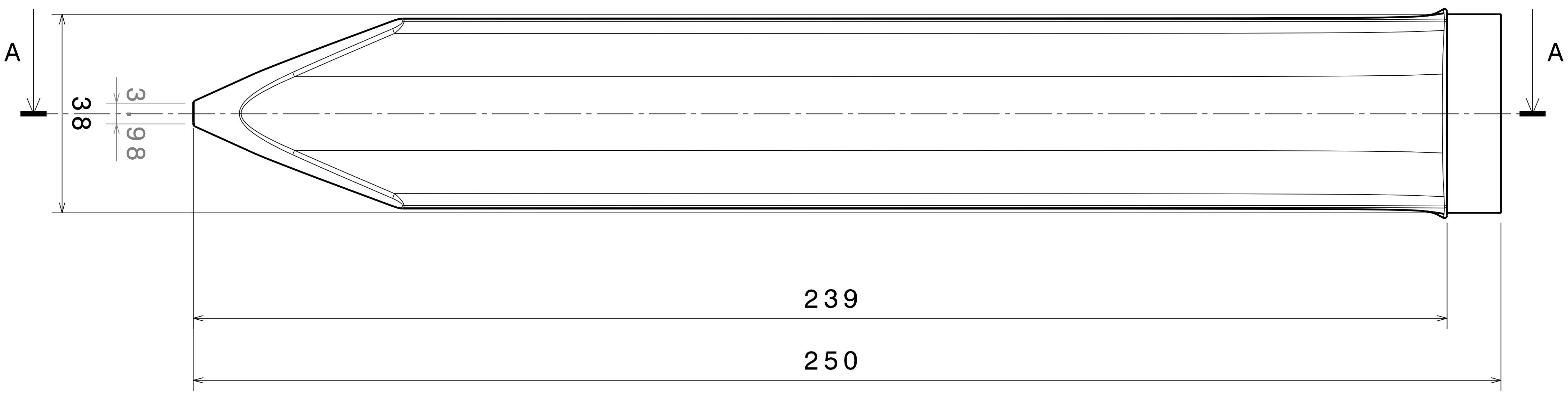
Isometric view

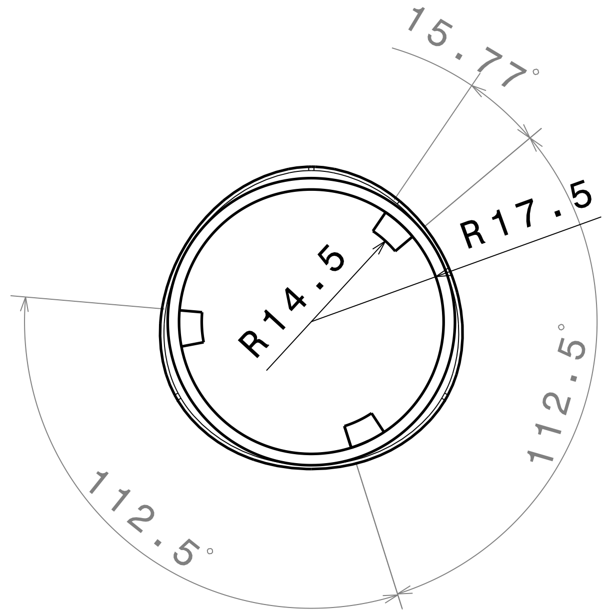


Undefined geometry acc. 3D model

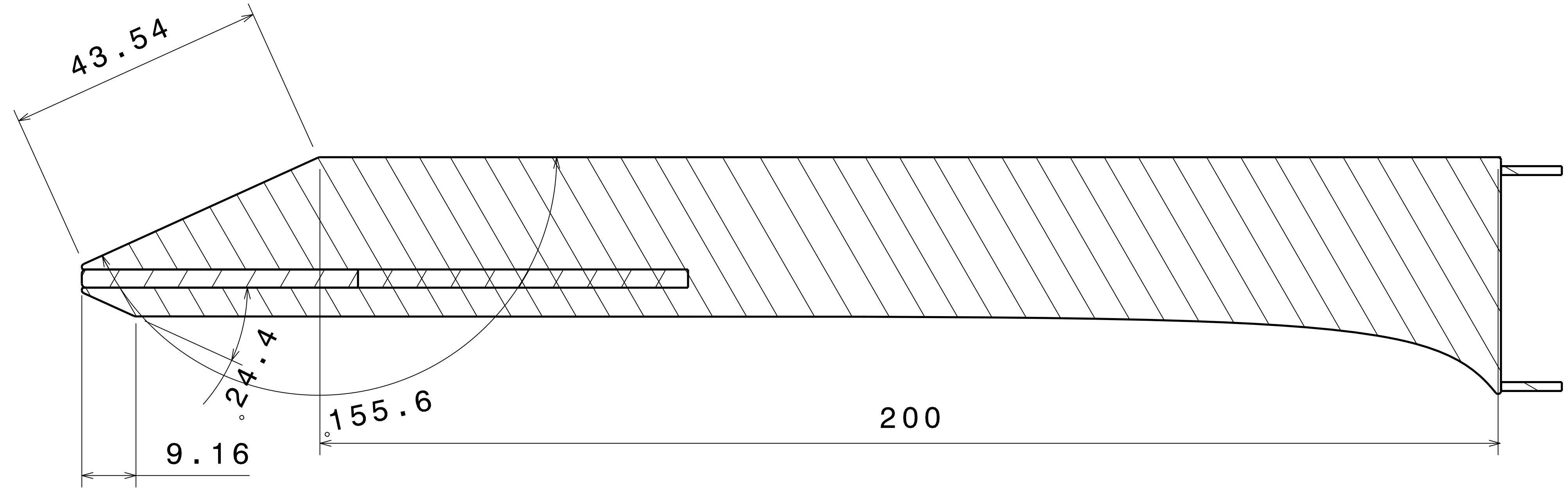
FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS			MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE		DESCRIPTION VIEWS and SECTION	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART STAKE 1	Nº 1/1		REV. B	DATA 20.09.2016	FOLHA 7/10

Front view

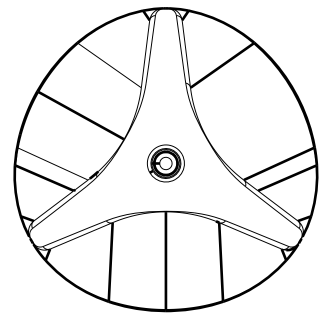




Top view



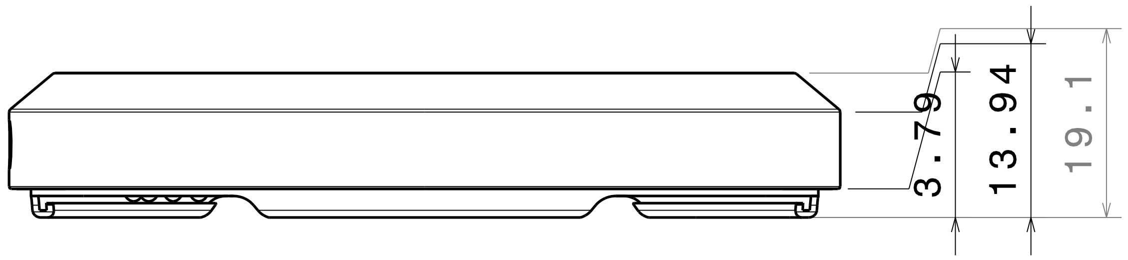
Section cut A-A



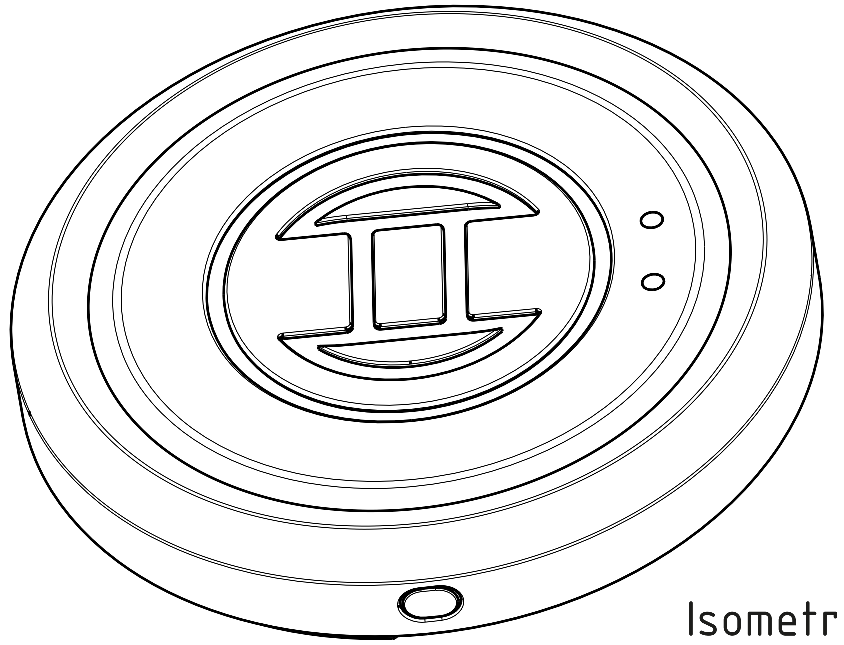
Bottom view

Undefined geometry acc. 3D model

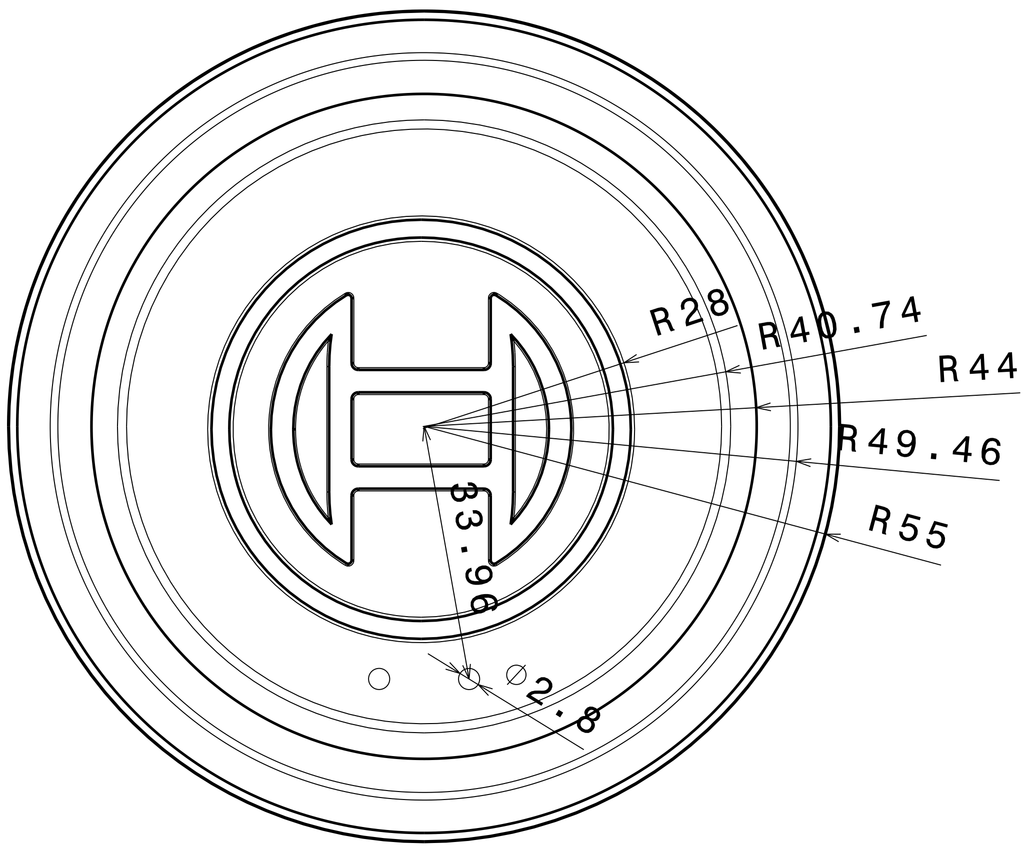
FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS			MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE		DESCRIPTION VIEWS and SECTION	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART STAKE 2	N° 1/1		REV. B	DATA 20.09.2016	FOLHA 8/10



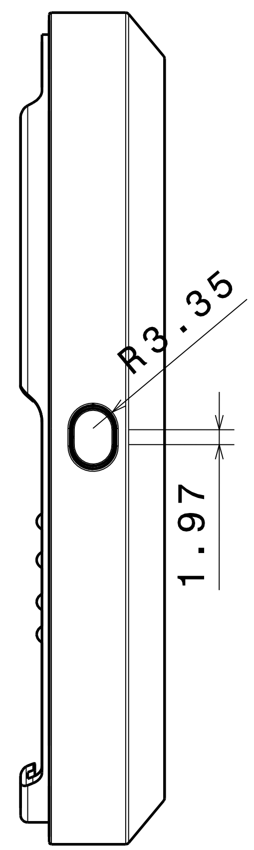
Front view



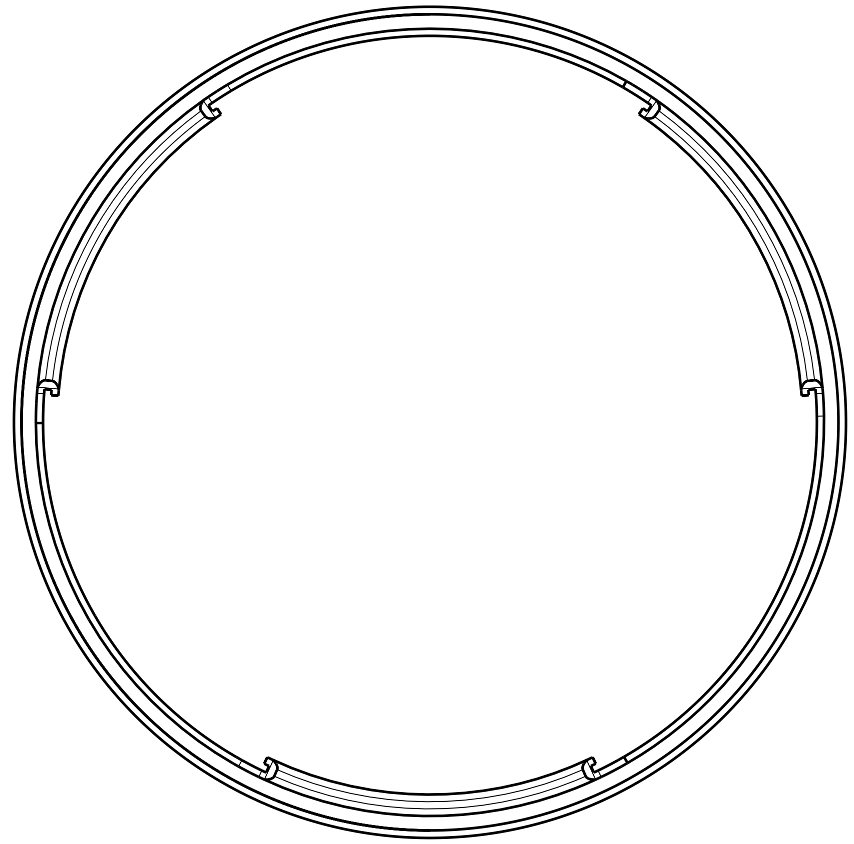
Isometric view



Top view

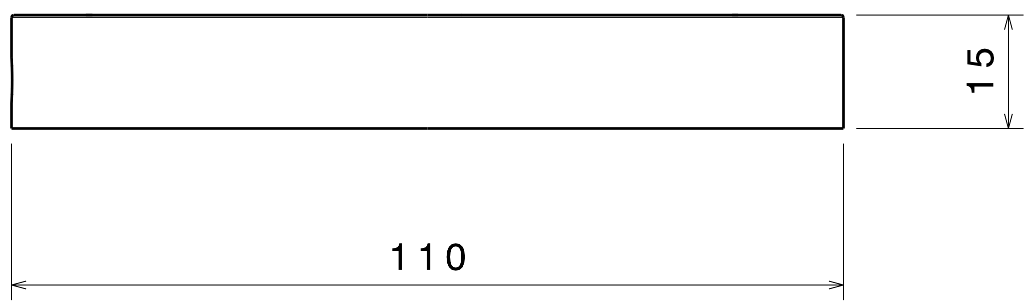


Rear view

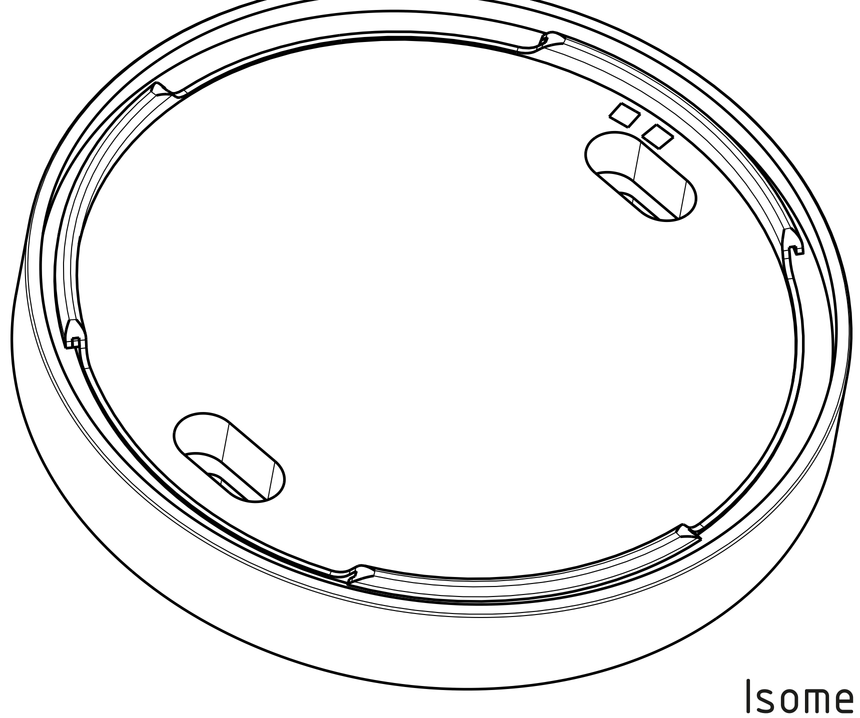


Bottom view

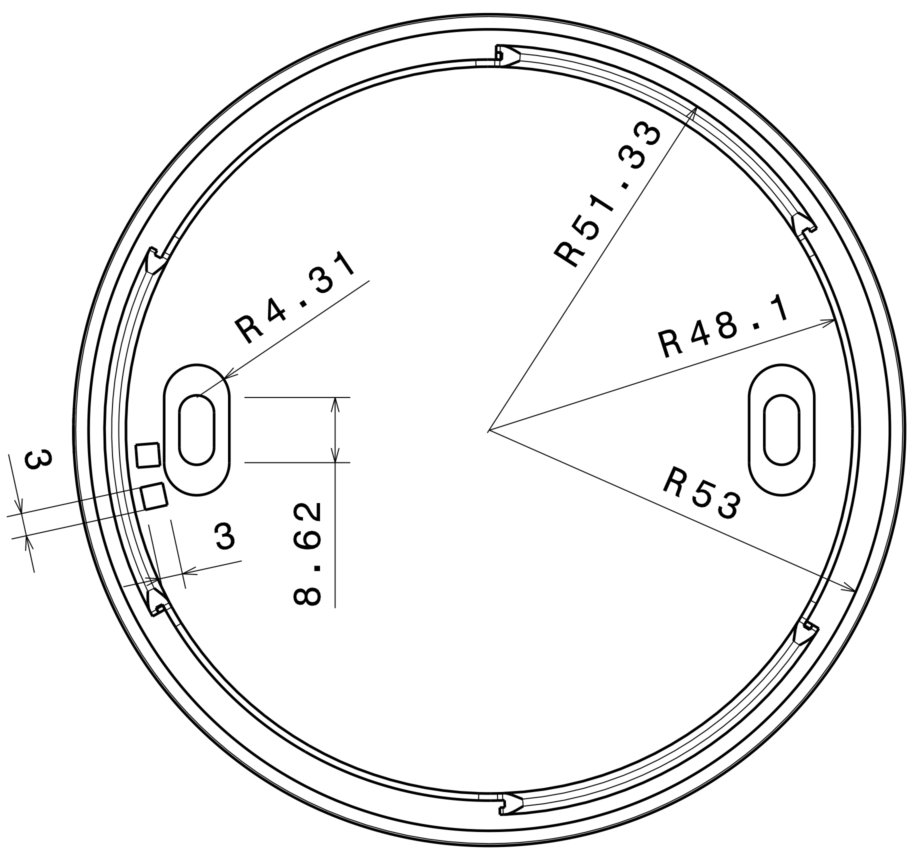
FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS		MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE	DESCRIPTION VIEWS and SECTION	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART TOP COVER	Nº 1/1	REV. B	DATA 20.09.2016	FOLHA 9/10



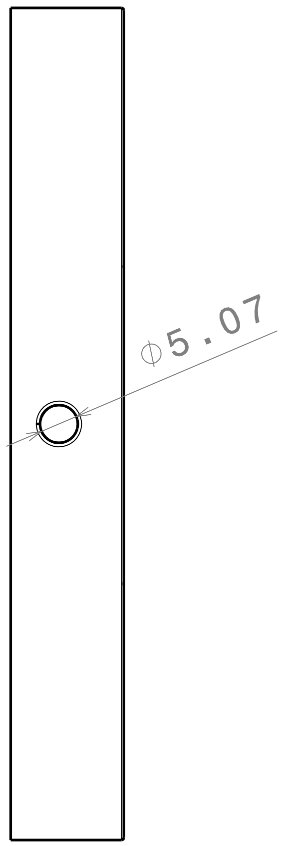
Front view



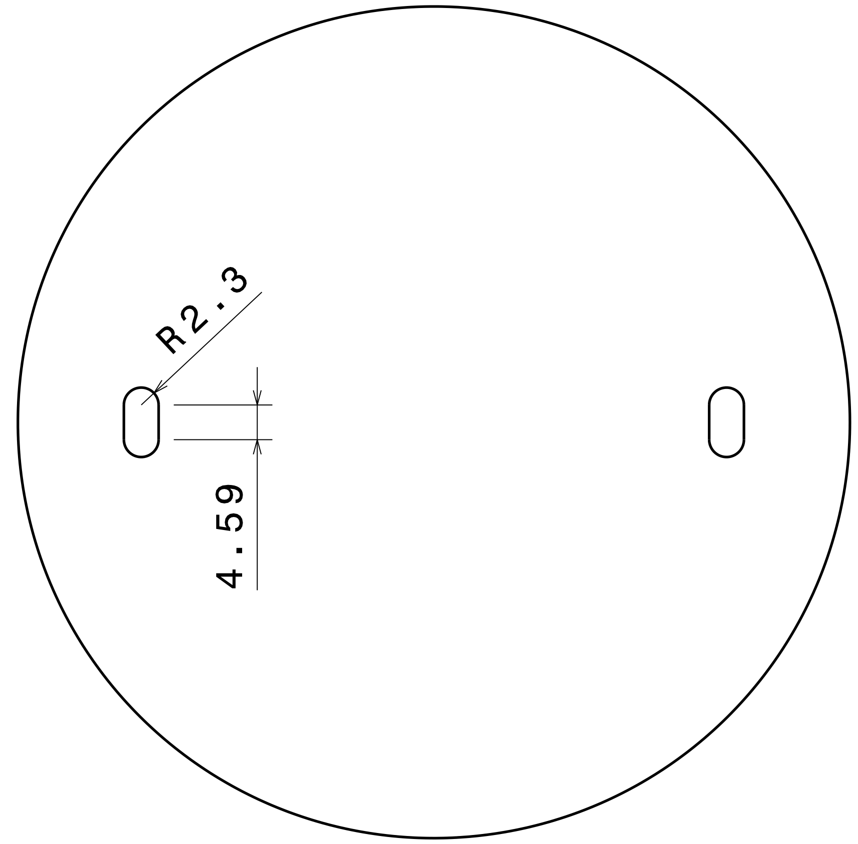
Isometric view



Top view



Rear view



Bottom view

FACULDADE DE ARQUITECTURA DA UNIVERSIDADE DE LISBOA	DRAWING BY ADRIANE WASSMANSDORF MATTOS		MASTER IN PRODUCT DESIGN THESIS		
	TITLE SENSOR DEVICE	DESCRIPTION VIEWS and SECTION	ESCALA 1:1	UNIDADE mm	TAMANHO A3
	PART WALL MOUNT	N° 1/1	REV. B	DATA 20.09.2016	FOLHA 10/10